



**CALIFORNIA
ENERGY COMMISSION**



Energy Research and Development Division

FINAL PROJECT REPORT

Integration of Advanced Solar Thermal Technology into Industrial Processes

December 2021 | CEC-500-2021-057

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ACKNOWLEDGEMENTS

The author thanks Treasury Wine Estates, Lloyd W. Aubry Company, Inc., Empowered Solutions LLC, pre-proposal advisement from UC Davis Department of Viticulture & Enology, the technical advisory committee, local businesses, and many other industry professionals for financial, engineering, and technical support for this project. The author is grateful to the California Energy Commission for guidance and support throughout the project.

The research team gratefully acknowledges the funding received from the California Energy Commission (Contract Number PIR-15-010) and Treasury Wine Estates in support of this research.

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division manages the Natural Gas Research and Development Program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with research, development, and demonstration entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater natural gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency.
- Industrial, Agriculture and Water Efficiency.
- Renewable Energy and Advanced Generation.
- Natural Gas Infrastructure Safety and Integrity.
- Energy-Related Environmental Research.
- Natural Gas-Related Transportation.

Integration of Advanced Solar Thermal Technology into Industrial Processes is the final report for the Integration of Advanced Solar Thermal Technology into Industrial Processes project (Contract Number PIR-15-010) conducted by ergSol, Inc. The information from this project contributes to the Energy Research and Development Division's Natural Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the [CEC's research website](http://www.energy.ca.gov/research/) (www.energy.ca.gov/research/).

ABSTRACT

The majority of industrial processes occur in a temperature range of 100° Fahrenheit to 300° Fahrenheit. Solar thermal systems can meet a significant portion of heating requirements in many industrial and commercial settings. However, the marketplace lacks data on the performance, costs, reliability, and flexibility of high-performance evacuated tube collector technology.

Integrating solar thermal systems into industrial processes offers companies a tremendous opportunity for reducing greenhouse gas (GHG) emissions, fuel consumption, and operating costs while remaining competitive in local and global markets. Market potential for industrial solar thermal applications is substantial and could contribute to California's GHG emission reduction goals to reduce GHG emissions to 40 percent 1990 levels by 2030.

ergSol designed an innovative high-efficiency solar thermal system with high-performing evacuated tube collectors called the "ergSol Integrated Solar Thermal System" for wine production. The solar thermal system with energy storage was integrated into the energy structure of the Treasury Wine Estates fully operating processing plant to maximize the use of solar thermal heat for the manufacturing process. The project featured a pump station that moved heated water from the collectors to the solar storage tank and from there to the existing boiler system and had a flexible modular design that afforded easy access for turnkey installation and system maintenance.

This research assessed the performance and validated the technical viability of the technology as a localized, energy-efficient measure for California's new and existing industrial operations and processes. The integrated solar thermal system in this project could annually save 11,291 therms of natural gas, reduce carbon dioxide emission by around 60 metric tons, and save \$10,387 in avoided natural gas costs. The project results could increase market acceptance and penetration, due to the system's replicability and scalability to other plants in similar settings across California and elsewhere.

Keywords: Solar thermal, evacuated tube collector, solar process heating, water heating

Please use the following citation for this report:

Dr. Weiss, Monika. 2021. *Integration of Advanced Solar Thermal Technology into Industrial Processes*. California Energy Commission. Publication Number: CEC-500-2021-057.

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EXECUTIVE SUMMARY

Introduction

California's industrial, agricultural, and water sectors annually use 30 percent of all natural gas consumed in the state, relying heavily on an affordable, reliable, and sustainable energy supply. This sector benefits from research that helps reduce energy use and cost, helps to meet environmental challenges, and accelerates the use of renewable resources while remaining competitive in local and global markets.

Among industries with high energy demands, specifically heat, California's \$50 billion food processing industry is an important, diverse, and dynamic sector of California's economy. According to the California Energy Commission (CEC), food processing is also the third-largest industrial energy user in the state (23 percent), with thermal energy demands of up to 80 percent of their total energy consumption. More than 600 million therms of natural gas and 3,700 million kilowatt-hours are consumed annually by this industry, including the electricity used in refrigerated warehouses. Integrating solar thermal systems into industrial processes offers companies an opportunity for reducing greenhouse gas (GHG) emissions, fuel consumption, and operating costs while remaining competitive in local and global markets.

Solar thermal refers to a variety of technologies capturing the sun's natural energy to produce heat energy. Collectors that gather radiation from the sun are a key element in all solar thermal applications, with a broad variety of available concentrating and non-concentrating solar thermal collectors. The solar thermal technology type varies with the temperatures needed for the end-use application. There are two main types of non-concentrating solar thermal collectors, flat-plate, and evacuated tubes. Evacuated tube collectors feature thin, copper tubes filled with a fluid, such as water, housed inside larger vacuum-sealed glass tubes, whereas flat-plate collectors feature copper tubing and other heat-absorbing materials inside an insulated frame or housing, covered with clear glazing.

California has one of the largest wine industries in the world. The state's 4,100 wineries produce more than 500 million gallons of wine per year, comprising about 90 percent of United States wine production and nearly 10 percent of the world's wine. Energy and water costs have increased rapidly for wineries located in California, making energy and water efficiency improvement an essential part of the business. Solar thermal systems could meet a significant portion of heating requirements for wine production, reducing energy costs, and lowering GHG emissions.

Project Purpose

The contractor, ergSol, Inc, developed and demonstrated the technical and economic feasibility of a commercial-scale integrated solar thermal system to generate on-demand thermal energy for industrial processes, displacing part of the natural gas use.

ergSol designed an innovative high-efficient solar thermal system with high-performing evacuated tube collector for wine production, the ergSol Integrated Solar Thermal System. The project team integrated the system with energy storage into the energy structure of the Treasury Wine Estates fully operating processing plant to maximize solar heat for the energy needed in the manufacturing process. The system's pump station moves heated water from the collectors to the solar storage tank, and from there to the existing boiler system, working

in conjunction with the solar controller to maintain consistently high efficiency. The pump station features a flexible modular design affording easy access for turnkey installation and maintenance.

The project is expected to increase market acceptance and adoption of solar thermal technology because the system can be replicated and scaled to other plants and similar settings across California and elsewhere. The benefits include long-term reductions in facility operating costs, GHG emissions, and reliance on fossil fuels.

The primary objectives of this project were to:

- Develop the design for a reliable, stable, and cost-efficient integrated solar thermal system to increase energy efficiency, reduce emissions, and minimize production costs.
- Fabricate and install the system into the operating process for full onsite use.
- Operate the system to generate quantifiable, objective performance data under real-world operating conditions.

Project Approach

ergSol partnered with Treasury Wine Estates in Sonoma, California, to integrate the solar thermal system into the industrial process at the winery's Sonoma Bottling Center, which produces more than 10.5 million cases of wine annually. Treasury Wine Estates receives bottle-ready wine from its wineries in California and around the world and packages the wine through four state-of-the-art bottling lines within the facility. The bottling process uses hot water by a clean-in-place system to sanitize and clean the production and cellar equipment. Clean-in-place is a method of cleaning interior surfaces such as process pipes, vessels, process equipment, filters, and associated fittings, without disassembly. The solar thermal project supplemented the energy required to produce hot water for the clean-in-place process.

Lloyd W. Aubry Company, Inc. was instrumental in installing and integrating the system into the existing boiler system. Empowered Solutions LLC supported the project during the design, construction, closeout, and measurement and verification phases. A monitoring system collected the measured data to quantify the impact of the solar thermal installation on natural gas consumption.

Figure ES-1 illustrates the integrated solar thermal system. The collectors are installed flush against a slightly sloped roof of a building, the solar storage tank is installed adjacent to the building, as well as the containerized pump station for the solar thermal system. The hot water from the tank is being piped (connected) to the existing hot water units, providing on-demand thermal energy.

Figure ES-1: Integrated Solar Thermal System



Source: ergSol, Inc.

The primary technical issues addressed were:

- Determining the size and fluctuation of the process heat loads and balancing the components for maximizing energy output.
- Designing the solar field that can most efficiently and safely satisfy those loads.
- Confirming that the facility's roof structure can support the collectors weight and wind load.
- Designing the solar thermal system that easily integrates into the customer's production processes.
- Addressing freeze protection and stagnation issues.
- Identifying a schedule of operation and developing control logic for the system.
- Identifying maintenance requirements.
- Establishing inspection protocols and keeping an inventory of critical spare parts.

ergSol formed a technical advisory committee composed of diverse professionals to guide the project direction, market applications, recommendations regarding information dissemination, market pathways, and commercialization strategies relevant to the project products. Committee members included experts from entities such as Sustainable Wine and Food Processing Center Department of Viticulture and Enology/University of California, Davis, Healthy & Resilient Buildings Department/San Francisco International Airport, Technology Implementation Office/Bay Area Air Quality Management District, Solano Economic Development Corporation, and Real Energy.

Project Results

The team designed, built, and operated a full-sized integrated solar thermal system at Treasury Wine Estates in Sonoma. The solar thermal system installed at the winery consisted of 240 evacuated tube collectors with 4,106 square feet of gross area, a 10,000-gallon storage tank with an energy capacity of 3.5 megawatt hours (MWh), and a flexible modular pump station. The large tank capacity was essential for providing on-demand heat energy for the industrial operation.

After commissioning the system, the project team adjusted and fine-tuned the system. The system operated reliably and safely after its commissioning. The initial five-week measurement and validation analysis showed a deviation between the actual energy data and the estimated energy baseline affected by seasonal circumstances. The performance during measurement and verification from February through early March corresponded to the lowest solar generation time of year. The solar generation is expected to increase in the summer, which will increase the amount of heat transferred to the process water. In addition to the thermal energy generation, the offset natural gas was calculated by how much thermal energy is transferred to the clean-in-place process water, which depends on how much water is being used. The low actual energy savings resulted due to lower hot water usage across the plant, directly related to the plant production capacity.

While real operating conditions significantly impacted the estimated energy baseline, the findings indicate that the integrated solar thermal system has the capacity to achieve 11,291 therms/year natural gas savings, 60 metric tons/year carbon dioxide emission reductions, and \$10,387 avoided natural gas costs per year based on CEC data and nameplate boiler 96 percent efficiency at the demonstration site.

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

The market potential for industrial solar thermal applications is substantial and could considerably reduce GHG emissions. Solar thermal systems have applications beyond food processing. The majority of industrial processes occur in a temperature range of 100°F to 300°F. ergSol's evacuated tube collectors can provide more than 300°F temperature heat with high efficiency, making them appropriate for industrial process heat needs. The collectors can also be used in cooling processes among various sectors that currently use electric chillers. Efficient solar thermal cooling — using sorption chillers powered by heat energy — is another efficient and promising use of solar thermal ST technology. Combining carbon-free heat with sorption chillers, natural refrigerants, and energy storage allows for maximum energy efficiency, elimination of ozone-depleting refrigerants, and overall air emissions reductions.

ergSol's ISTS delivers excellent siting flexibility while providing a significant portion of heating requirements in many industrial and commercial settings. The most promising industry sectors suitable for solar thermal include food and beverage, dairy, poultry and agricultural products, pharmaceuticals, textiles, hospitality, and hospitals.

This project provided real-world data on the technical and economic feasibility, reliability, and durability for solar thermal systems to overcome the primary obstacle to wide-scale deployment: customers will only invest in projects that use proven technology. The data and results from this demonstration will support risk reduction by customers operating and

financing this technology. The project will provide a foundational justification for future utility rebate and incentive programs, energy codes and standards, and securing private capital and other funding to develop and improve the technology.

Interdisciplinary collaboration is critical to accelerating the deployment of advanced solar thermal systems for diversified applications in the industrial sector. Throughout the project, the team engaged with a wide variety of stakeholders, including industry, installers, customers, vendors, and regulators. A key component of technology transfer will be in the meticulous collection and analysis of information from the demonstration project. The team developed a technology transfer plan and dissemination strategy to communicate specifically with the food processing industry, educational institutions, and community organizations about the potential of an integrated solar thermal approach.

Prior to receiving the CEC grant, ergSol reached out to various audiences to create awareness about solar thermal integration potentials to meet California's energy and GHG emission goals. Stakeholders included:

- Academia, air quality management districts, the California Air Resources Board, the CEC, the Workforce Development Agency, and the Small Business Administration.
- Food processors, real-estate developers, architects, mechanical and structural engineering firms, construction companies, plumbers, heating, ventilation, and air conditioning contractors, installers, electricians, roofer, building inspectors, building commissioners, welders, insulators, vendors for solar thermal components, facilities and building operators, and various service providers.

Benefits to California

Highly efficient solar thermal systems may contribute multiple benefits to California, from the environment to the economy. A primary focus of this project was to show how solar thermal systems can offset the use of natural gas, resulting in fewer carbon emissions and lower natural gas costs. Environmental benefits include reductions in GHG emissions that could assist with global climate change objectives, reduced public health risks, and minimized impacts on the state's natural resources related to energy generation and consumption. High-performance solar thermal systems are suited for integration into industrial processes and buildings to supplement on-site demand for thermal loads. All these benefits can have measurable effects on California's aggressive energy efficiency goals.

The demand for heat plays a significant role in industrial energy demand. ergSol's simulation indicates that its integrated solar thermal system could save about 13,200 therms of natural gas per year. These savings can account for 70.2 metric tons of local GHG emission reductions and \$12,144 avoided costs for natural gas. Simulation assumptions were based on an 82 percent boiler efficiency according to the California Solar Initiative Thermal Program; an emission factor (carbon dioxide equivalent) of 11.7 pounds per therm saved; and industrial sector natural gas costs of \$0.92/therm as outlined in GFO-16-502 Attachment 13—References for Calculating Energy End-Use, Electricity Demand and GHG Emissions.

Assuming 30 percent of the natural gas use in the food processing sector could be offset by solar thermal, the natural gas savings would be 180 million therms per year, reducing GHG emissions by 955,800 metric tons. The estimated levelized cost of heat for the Treasure Wine Estates project is \$4.28 per therm as documented in the 30-year cost analysis. However, the

estimated levelized cost of heat for similar installations is \$1.18 per therm, being competitive with natural gas systems and very attractive against a potential rise in gas prices. Guidelines for the integration of large solar heating systems in industrial settings would be beneficial for accelerating market penetration.

Benefits are beyond just the cost of energy and greenhouse gas emission reductions. Solar thermal energy can be a significant source for state-level economic benefits that include jobs, lease payments, and business activities. The jobs created are (a) in research and development; (b) supporting the design, development, construction, and installation of the solar thermal systems; (c) jobs in the manufacturing, the associated supply-chain sectors, and sales; and (d) operational related jobs from purchasing equipment and materials and services necessary to keep the installed systems operating.

CHAPTER 1:

Introduction

Thermal Energy for Industrial Processes

Thermal energy is a ubiquitous need for industrial processes, making solar thermal water heating systems a promising clean, and environmentally friendly technology for replacing part of NG. The employment and integration of ST technologies for industries with high thermal energy demand is a viable and sustainable solution for meeting the California carbon reduction goals and decreasing natural gas use. However, the marketplace currently lacks data on the costs, performance, reliability, and flexibility of its integration into current operational industries.

Among industries with high energy demands, California's \$50 billion food processing industry is an important, diverse, and dynamic sector of California's economy. Integrating ST systems into industrial processes offers companies an opportunity for reducing GHG emissions, fuel consumption, and operating costs while remaining competitive in local and global markets.

"California's 570,000 acres of wine grapes and 4,100 wineries produce more than 500 million gallons of wine per year, comprising about 90 percent of US wine production, and nearly 10 percent of the world's wine" (Styles 2014). "Energy and water costs have increased rapidly for wineries located in California, making energy and water efficiency improvement an essential part of the business" (Galitsky 2005). ST systems can meet a significant portion of heating requirements for wine production, and this industry represents a well-focused market segment that can readily exploit this project approach once it is technically and economically proven.

The advantages of employing ST technologies in California's food industry was assessed for CEC by the University of California at Davis (UCD) researchers in 2006 (CEC 2006). ST's promising advantages for replacing part of the natural gas consumption for process heat demand were recognized; hence, its environmental benefits brought this technology into focus as a solution for other California industries that have high process heat demand. The market opportunities, technologies, and case studies by researchers showed that

- Solar thermal technologies are promising for California industries with high thermal load demand.
- One of the main challenges in the employment of ST technologies is their integration into current operational industries.

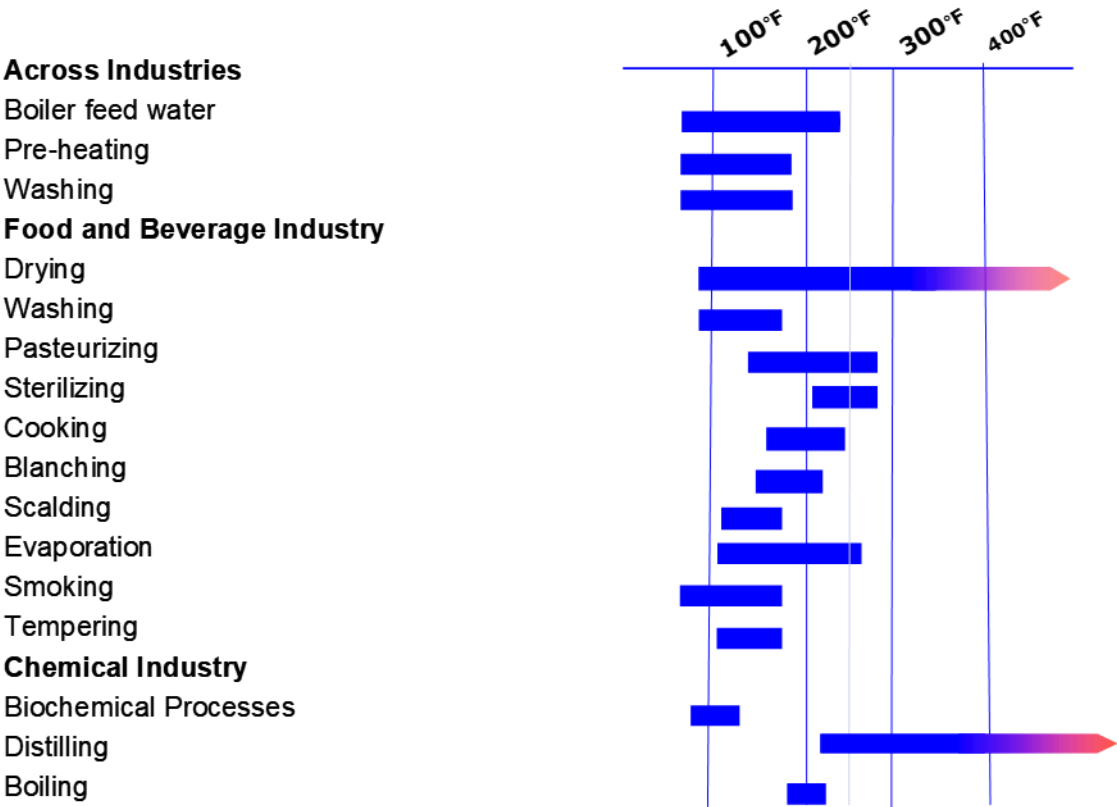
Based on these studies, the large thermal energy demand of the food processing industry makes it one of the significant target markets for ST technologies. The project team partnered with Treasury Wine Estates, highly regarded for its leadership in the industry and environmental stewardship. Leading experts from the UCD Department of Viticulture and Enology provided pre-proposal advisement on state-of-the-art technologies in the wine and food industry. The project demonstrates how the integration of an ST system into existing operations can be a cost-effective and energy-efficient strategy. In turn, this project could guide future design and application into similar industries.

Solar Thermal Technology

The sun’s energy arrives at Earth primarily in the form of heat. ST technology collects, stores, and distributes that heat most efficiently. This heat can be used to heat air or a transfer fluid. This process significantly offsets the use of fossil fuels, including natural gas or utility-generated power. At the same time, there are immediate reductions in greenhouse gas emissions from eliminating these energy sources. Solar thermal energy is a solution that can be customized and optimized for many applications, providing a carbon-free heat source for heating and cooling systems.

Optimized use of thermal energy is widely applicable for industrial processes that require heat in various temperature ranges. The vast majority of industrial processes occur in a temperature range of 100°Fahrenheit (F) to 300°F (IEA-ETSAP and IRENA 2015). This temperature “sweet spot” is standard in most industrial sectors, including food and beverage; dairy, poultry and agricultural products; pharmaceuticals; textiles; paper; metal surface treatment. All of these need pre-heated water for boilers, air conditioning, sanitation treatment, and other heat demanding processes. Figure 1 provides an overview of suitable industrial processes and temperature levels for ST applications.

Figure 1: Industrial Processes and Temperature Levels



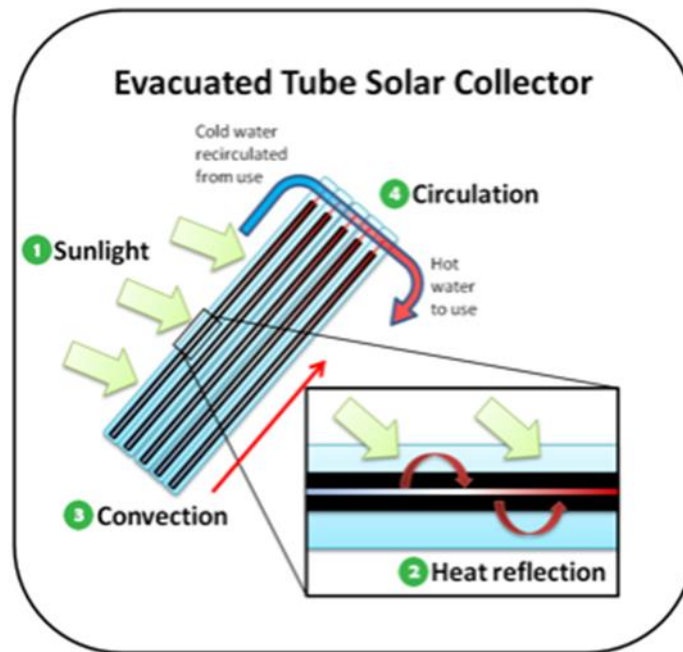
Source: Reproduced from IEA-ETSAP and IRENA 2015 and other data collected as part of this project

Collectors, which gather the sun’s radiation, are a key element in all solar thermal applications. The mounted solar thermal collectors harness the free and readily available solar energy to heat transfer fluid inside the collectors. The solar radiation is transformed into heat energy within the fluid, providing carbon-free heat energy to the industrial application. Evacuated

tube collectors feature thin, copper tubes filled with a fluid, such as water, housed inside larger vacuum-sealed glass tubes.

The United States Environmental Protection Agency (EPA) provides basic information on how evacuated tube solar collectors work (Figure 2).

Figure 2: How It Works



Source: <https://www.epa.gov/rhc/solar-heating-and-cooling-technologies#Evacuated tube solar collectors>

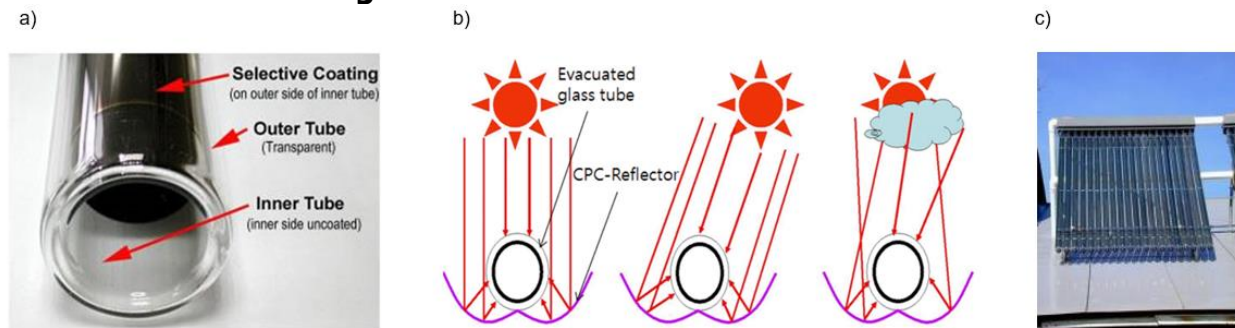
How it works:

1. Sunlight: Sunlight hits a dark cylinder, efficiently heating it from any angle.
2. Heat reflection: A clear glass or plastic casing traps heat that would otherwise radiate out. This is similar to the way a greenhouse traps heat inside.
3. Convection: A copper tube running through each cylinder absorbs the cylinder's stored heat, causing the fluid inside the tube to heat up and rise to the top of the cylinder.
4. Circulation: Coldwater circulates through the tops of the cylinders, absorbing heat.

The most common type of evacuated tube collectors are double-walled glass tubes. The *double-walled glass tube* (Figure 3) consists of two concentric glass tubes that are half spherically closed on one side and fused together on the other side.

- a) The space between the glasses is evacuated. The external surface of the inner glass tube is coated with a selective coating material for harvesting solar thermal energy. The heat absorbed by the inner glass tube is transferred via a thin water-carrying metal tube.
- b) Compound Parabolic Concentrator (CPC) placed under the tubes is used many times to increase the efficiency of the evacuated tubes. The CPC ensures that unfavorable direct irradiation angles and diffusion irradiation will fall to the absorber coating.
- c) The tilt angle for installation is influencing the amount of energy collected by a solar thermal collector with respect to the horizontal.

Figure 3: Double-Walled Glass Tubes



Source: a) www.designingbuildings.co.uk; b) www.e-sciencecentral.org ; c) [https://www.epa.gov/rhc/solar-heating-and-cooling-technologies#Evacuated tube solar collectors](https://www.epa.gov/rhc/solar-heating-and-cooling-technologies#Evacuated%20tube%20solar%20collectors)

ergSol's collector is made of *single-walled glass tubes* that contain a metal absorber fin. The fin is covered with a selective coating that absorbs solar energy highly efficient but inhibits radiative heat loss. Air is removed or evacuated from the glass tubes to form a vacuum, which mitigates conductive and convective heat loss. The solar radiation transmits through the glass and heats the absorber's fin, which transfers the heat energy to the heat exchanger pipe, and the energy will be collected in the manifold. The evacuated tubes are equipped with a visual indicator to give the integrity of the vacuum. Those collectors can be installed flat/horizontally on roofs/grounds or vertically on the façade of a building. The product's building-integrated design maximizes function and reduces visual impacts associated with many solar technologies. Since the absorber fin inside the glass tube is adjusted to the optimum tilt angle for the geographical location, there is no need to tilt the collectors. Details of the ergSol collector 100-6df are illustrated in Figure 4:

Figure 4: ergSol Collector 100-6df



Source: ergSol, Inc.

ergSol's high-performance ETCs represent non-concentrating design without the need for additional complexity of tracking systems. These collectors can provide more than 300°F heat with high efficiencies, making them appropriate for industrial process heat use as well as an alternative where electric chillers are currently used for product cooling. Efficient solar thermal cooling - using sorption chillers powered by heat energy - is another efficient and promising use of ST technology. Combining carbon-free heat with sorption chillers, natural refrigerants, and energy storage allows for maximum total energy efficiency, elimination of ozone-depleting refrigerants, and overall air emissions reductions.

ergSol's collector has been OG-100 certified by the U.S. Solar Ratings and Certification Corporation (SRCC) – the authoritative solar thermal performance rating organization for the U.S. market. Solar collectors are certified to the requirements of International and Uniform Codes and Standards (ICC 901/SRCC 100 Solar Thermal Collector) with the intention of protecting and providing guidance to consumers, incentive providers, government, and the industry. OG-100 certification ensures that collectors meet minimum safety and durability criteria. It also provides standardized performance ratings for different climate types and applications. Based upon SRCC data, the following equations were used to provide collector efficiency based on the absorber area.

Equations:

$$\eta = \eta_0 \kappa(\Theta) - c_1 \frac{\Delta T}{G} - c_2 \frac{\Delta T^2}{G}$$

$$\kappa(\Theta) = \kappa_{\text{LONG}}(\Theta) * \kappa_{\text{TRANS}}(\Theta)$$

Where

G = Global Irradiation

A_{coll} = Collector Area

C_1 = Heat Loss Coefficient

C_2 = Temperature Dependable Heat Loss

$\kappa_{\text{LONG}}(\Theta)$ = Incident Angle Modifier for Longitudinal Axis for the Collector

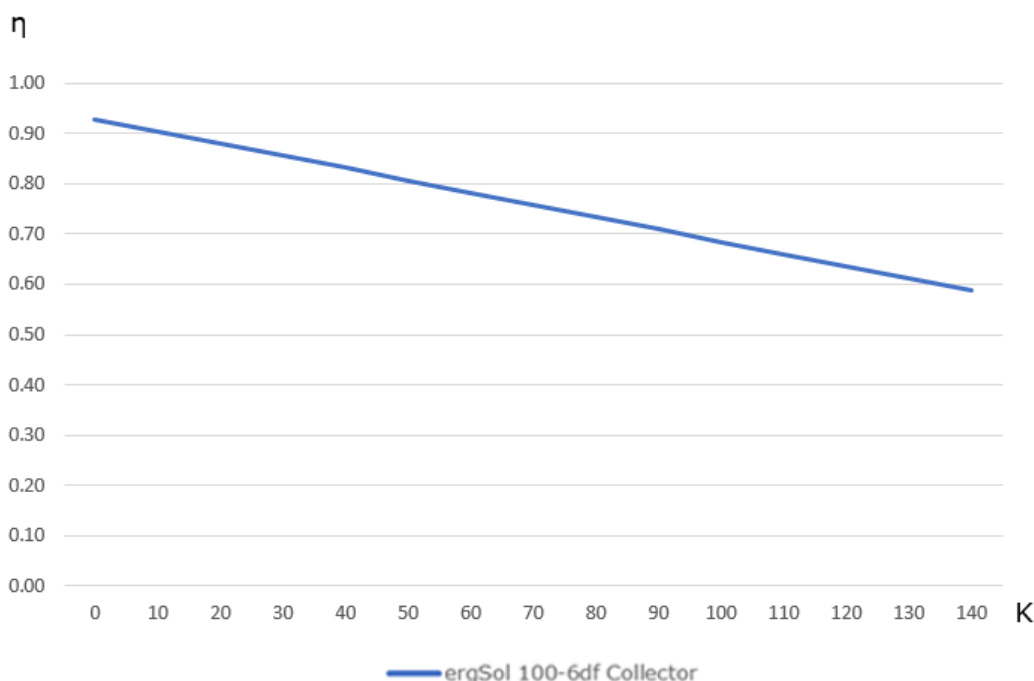
$\kappa_{\text{TRANS}}(\Theta)$ = Incident Angle Modifier for Transversal Axis of the Collector

Figure 5 shows ergSol 100-6df collector efficiency. The greater the temperature differential between collector and outside air (K), the greater the thermal losses – the efficiency therefore falls with the rising operating temperature of the collector or with the drop in the outside air temperature.

ergSol is integrating an innovative solar thermal system, based on ergSol's high-performance ETCs, into an existing industrial application. Those ETCs represent localized, non-concentrating, non-tracking ST design. These collectors provide high temperatures with high efficiency. They are designed to be mounted flat on surfaces, leading to a small footprint for collector installation. Roof real-estate is often in short supply, and a smaller footprint per high-temperature BTU translates into more savings. Due to the absence of CPC reflectors underneath the ergSol collectors, the maintenance costs - especially regular cleaning – are lower than those for CPC collectors.

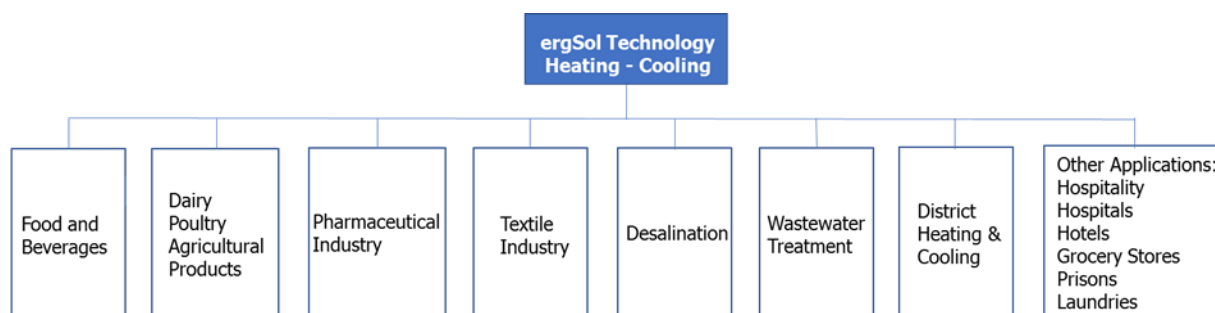
ergSol manufactures its high-performance ETCs in California, the first in the state, according to the California Secretary of State's website (SOS). Proving the technology in real-world conditions will foster acceptance, innovation, and generate a significant domestically produced clean-technology industry. The most promising industry and commercial sectors suitable for ST are shown in Figure 6. ST systems present a valuable opportunity to reduce peak energy load and natural gas consumption while expanding the solar thermal industry in California. More details on ergSol's technology are provided in Chapter 2.

Figure 5: Collector Efficiency Based on Absorber Area



Source: ergSol, Inc.

Figure 6: Versatile Applications for ergSol's Technology



Source: ergSol, Inc.

ST technology is an under-used renewable resource, and optimization of ST technologies for maximizing energy efficiency for industrial and commercial applications (buildings and processes) has scarcely been addressed. Localized ST applications are a valid and viable means of reducing the need for conventional primary energy sources. However, many people are simply not aware of the full range of ST applications. The International Energy Agency (IEA) estimates by 2050 - with concerted action by all stakeholders globally - the potential for solar industrial process heat (SIPH) to contribute up to 7.2 exajoules (EJ) per year (equivalent to 6.7 percent of U.S. energy consumption by EIA 2018) based on an installed capacity of more than 3,200 GW_{th} in industrial low-temperature applications up to 120°C (equivalent to 248°F). Final energy demand for low-temperature process heat in the industry will increase to 35.5 EJ by 2050, with low-temperature solar process heat accounting for 20 percent of total energy use for low-temperature industrial heat.

Project Goals and Objectives

The project goal was to demonstrate the technical feasibility and economic feasibility of a commercial-scale integrated ST system to generate on-demand thermal energy for industrial processes, displacing part of the natural gas use.

ergSol designed an innovative high-efficient ST system with high-performing ETCs for wine production. The ST system with energy storage has been integrated into the energy structure of Treasury Wine Estates' fully operating processing plant to maximize the use of ST heat for the heat needed in the manufacturing process. The pump station features a flexible modular design affording easy access for turnkey installation and maintenance. This research assessed the performance and validated the viability of the technology as a localized, energy-efficient measure for an industrial operation.

The project is expected to increase market acceptance and penetration, due to the system's replicability and scalability to other plants and similar settings across California and elsewhere. Importantly, long-term reductions in facility operating costs, GHG emissions, and reduced reliance on fossil fuels would also result from the project. Natural gas ratepayers would benefit immediately with a lower monthly bill.

The primary objectives of this project were to:

- Develop the design for a reliable, stable, and cost-efficient ISTS to increase energy efficiency, reduce emissions, and minimize the production costs.
- Fabricate and install the ST system into the operating process for full on-site use.
- Operate the system to generate quantifiable, objective performance data under real-world operating conditions.

The technology's applications are not limited to the food processing industry. Once commercialized, solar thermal systems can provide clean and cost-effective energy for various applications, all with a positive effect on reducing GHG emissions, conventional fuel consumption, and operating costs while remaining competitive in the marketplace.

CHAPTER 2:

Project Approach

The Host Site

Treasury Wine Estates (TWE) is one of the world's largest wine companies, listed on the Australian Securities Exchange (ASX.TWE). The company has a rich heritage and a portfolio of some of the most recognized and awarded wine brands in the world. TWE is committed to driving environmental sustainability and efficiencies within their supply chain and is working towards ensuring their environmental impact is sustainable over time. Energy management is critical to TWE's wine production. TWE recognizes the importance of managing energy sourcing, use, and efficiency as a part of operating sustainably, safely and responsibly. TWE is unique in that it utilizes renewable sources for energy. Of the total electricity consumed at their US wineries and bottling centers from off-site sources, almost 50 percent is from renewable energy, which equates to approximately 9 GWh per year. TWE continues to investigate energy sources and invests in innovation and technology for improving energy efficiency. Adding an innovative ISTS is a natural fit and will further maximize energy efficiency. This transformative energy efficiency technology is designed to be cost-effective as a direct supplement for legacy boiler systems allowing for lower investment and installation costs as operations expand.

The TWE site for the ST project demonstration is located at 21468 Eighth Street East, Sonoma, California. The advanced solar thermal technology was integrated into the industrial processes of TWE's Sonoma Bottling Center that produces in excess of 10.5 million cases of wine annually. The company receives bottle-ready wine from its wineries across California and around the world. This wine is packaged through four state-of-the-art bottling lines within the facility. The solar thermal project will supplement the energy needed to create hot water for the CIP process. Hot water is used throughout the bottling process for sanitizing and cleaning the production and cellar equipment, clean-in-place system.

Solar Thermal System Analysis

The integration of the solar thermal system into the industrial process at TWE required the analysis of the existing heat supply, energy flows, temperature levels of the process, and determining the potential energy savings. The ST project will supplement the energy needed to create hot water for the CIP process.

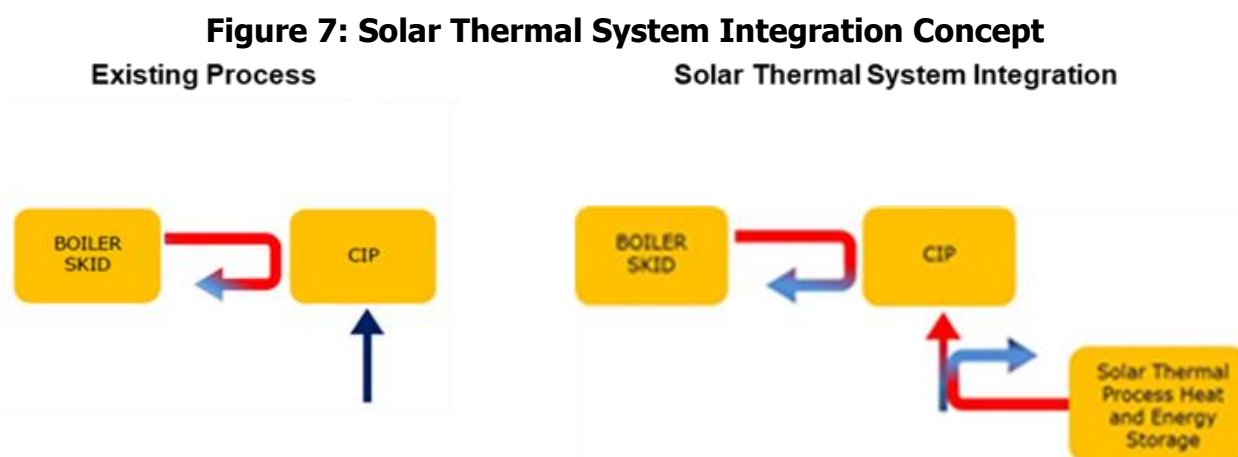
The primary technical issues addressed during the project are summarized and described in more detail in the following sections.

- Determining the size and fluctuation of the process heat loads and balancing the components for maximizing energy output.
- Designing the solar field that can most efficiently and safely satisfy those loads.
- Confirming that the facility's roof structure can support the collectors weight and wind load.
- Designing the solar thermal system that easily integrates into the customer's production processes.

- Addressing freeze protection and stagnation measures.
- Identifying a schedule of operation and developing control logic for the system.
- Establishing inspection protocols and keep an inventory of critical spare parts.

Integration of Solar Thermal System into the Production Process

The existing boiler system (Domestic Hot Water – DHW - Loop) provides thermal energy to the clean-in-place system (CIP) to sanitize and clean the production and cellar equipment. CIP is a method of cleaning interior surfaces, such as process pipes, vessels, process equipment, filters, and associated fittings, without disassembly. The sanitary aspects of producing food and beverage products are of extreme importance and plants must meet high hygienic standards to avoid a product's degradation and contamination. The solar thermal system was integrated to preheat and store the thermal energy until needed for the cleaning process. Figure 7 illustrates the integration concept.



Source: ergSol, Inc.

The CIP process schedule and load remains consistent throughout the year with the following schedule: Monday through Thursday is 3,900 gallons/day and 9,500 gallons/day on Friday with no consumption on Saturday, Sunday, and Holidays. A thermal energy storage tank was integrated into the design to extend the solar energy into the evening/early morning hours as well as for capturing the energy over the weekend, thereby increasing year-round energy and cost savings.

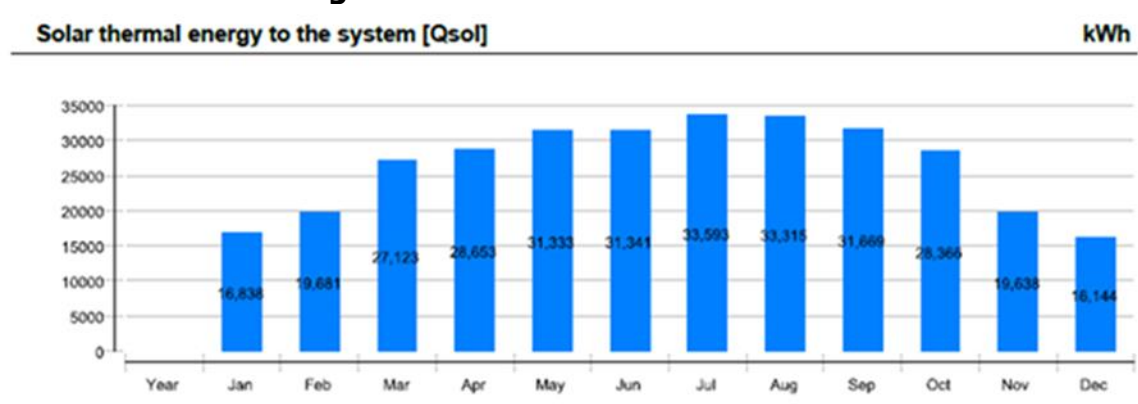
Evaluation and Assessment

In developing the design and layout of the ST system to maximize heat use, increase energy efficiency, reduce emissions, and minimize the production costs, a preliminary simulation with Polysun software was used. Polysun Software from Vela Solaris AG, is a software platform for the simulation-based planning, designing, and optimizing of comprehensive energy systems for buildings and districts.

A tilt of 35° of absorber area for the location and boiler efficiency of 82 percent was assumed according to the California Solar Initiative Thermal Program (CSIT) guidance. Emission Factor (CO_{2e}) of 11.7 lbs/therm saved and industrial sector natural gas costs of \$0.92/therm were used as outlined in GFO-16-502 Attachment 13–References for Calculating Energy End-Use, Electricity Demand and GHG Emissions (CEC 2016). An estimated installed collector gross area of 4,106 sq.ft. is expected to save 13,200 therms/year and 70.2 metric tons/year of carbon

dioxide (CO₂) emissions. Figure 8 shows the initial simulation results on the solar thermal energy to the system.

Figure 8: Initial Simulation Results



Source: ergSol, Inc. Polysun Simulation

Table 1 provides details on the simulation predicted performance estimate of the solar thermal installation consisting of 240 collectors with an estimated 4,106 sq.ft. gross area. The realized energy savings reduce the natural gas consumption due to the reduced load on the boiler plant.

Table 1: Initial Simulation Predicted Performance Estimate

	Annual Generation (MMBtu/yr)	Offset Natural Gas Savings (therms/yr)	Annual Reduction of CO ₂ Emissions (lbs/yr)	Avoided Costs (\$/yr)
Solar Thermal Installation (Based on average 82% boiler efficiency)	1,084	13,200	154,709 (70.2 metric tons/yr)	12,144

Source: ergSol, Inc.

More detailed information on the solar thermal calculations that refers to ergSol's ETCs:

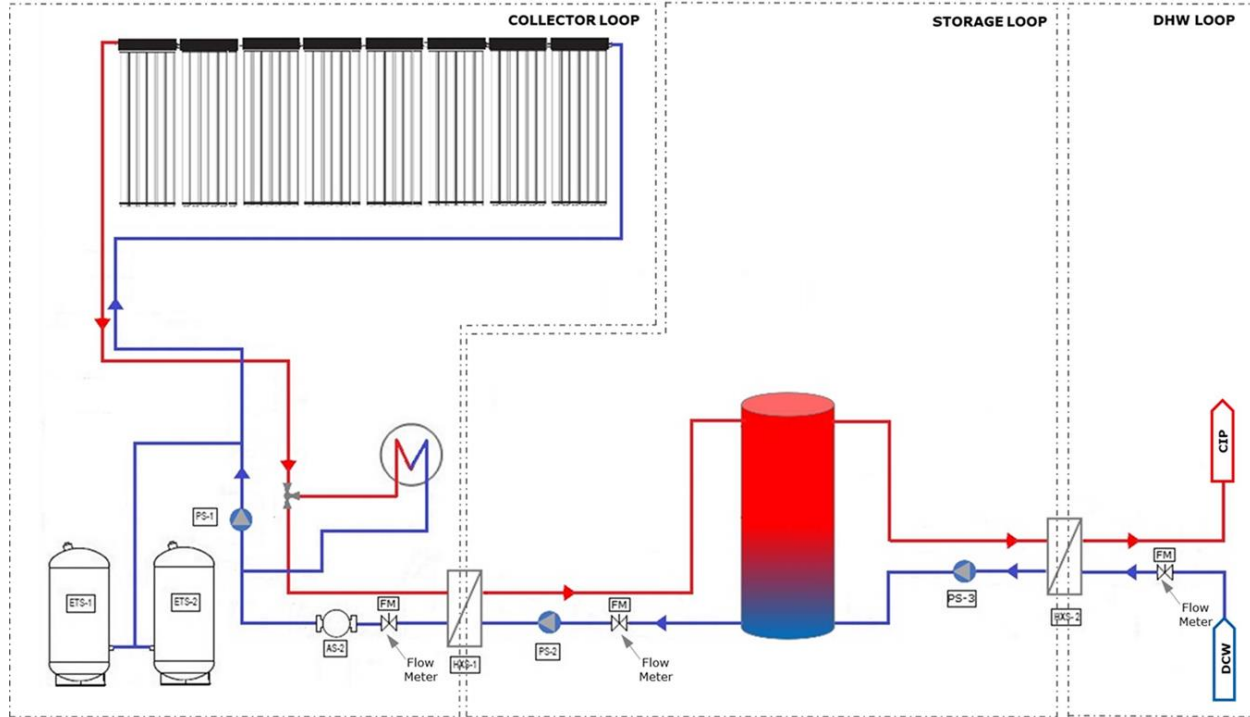
- Collector Gross Area: outer dimensions of the collectors, 4,106 sq.ft.
- Absorber Area: describes the absorber area, 2,769.6 sq.ft exclusively.
- Installation Area: ergSol collectors are installed flat on the roof; no need to tilt the collectors and, therefore, shading issues do not need to be considered. Installation area for ergSol collectors is at a minimum to be added to gross collector area (approx. 20 percent) – room added for piping and walkway, 4,926 sq.ft.

Integrated Solar Thermal System Design

ergSol's ISTS design was developed for a reliable, stable, and cost-efficient integration of the solar thermal system into the industrial thermal processes to supplement natural gas as the fossil fuel source. The fabricated heating system was made capable of mass production,

scalability, and adaptability to diverse market needs. The ST system was installed into the building's existing operational processes for full on-site use. The fundamental elements of the industrial solar thermal system include solar thermal collectors, storage tank, piping systems, heat exchangers, and control mechanisms. Details on the ergSol ISTS design are shown in Figure 9 and are described in more detail in the following sections.

Figure 9: ergSol Integrated Solar Thermal System Design



Source: ergSol, Inc.

The solar thermal system uses solar energy gathered from ergSol collectors to pre-heat the boiler feedwater for their operations. Use of the boiler system and solar thermal heat will be maximized for the industrial thermal needs; thereby, maximizing the overall system efficiency and the value for the user. The system is designed as a closed-loop system with water serving as the transfer fluid. Water has a high specific heat capacity as well as environmentally benign attributes.

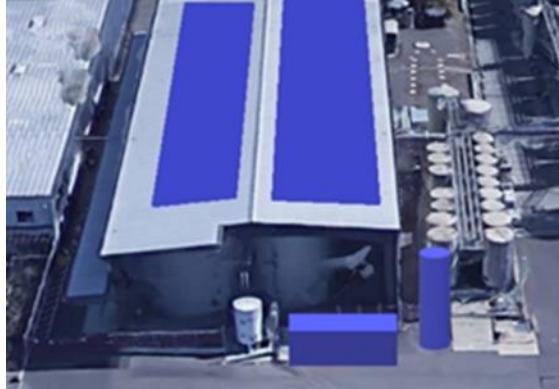
Heat storage provides advantages when there is a mismatch between thermal energy supply and energy demand. An atmospheric, cost-efficient thermal energy storage tank was integrated into the design to extend the solar energy into the evening/early morning hours as well as capture the energy over the weekend, thereby increasing year-round energy and cost savings. Water is used to store heating energy.

Ensuring that any available energy is delivered to the CIP system, a control mechanism is integrated into the active solar thermal system to control the collector loop, storage loop, and domestic hot water loop. Measurement devices, such as temperature sensors, solar radiation sensors, flow meters, and pressure sensors, are installed throughout the system to monitor and control the performance and maximum efficiency of the system.

Design and Layout

ergSol collectors are installed flush against a slightly sloped roof of a building. Shading issues do not need to be considered. A 10,000-gallon tank is installed adjacent to the building, as well as the containerized pump station for the solar thermal system. The hot water from the tank is piped (connected) to the existing hot water units, providing on-demand thermal energy. Figure 10 shows the location for the major ST system components, such as collector field, storage tank, and pump station.

Figure 10: Location for Major Solar Thermal System Components



Source: ergSol, Inc.

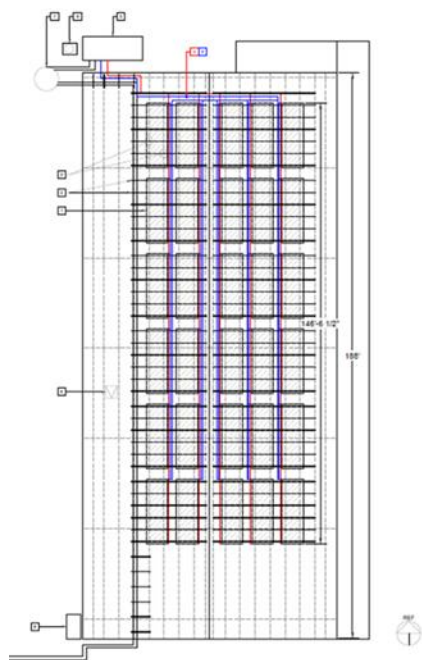
A location layout plan illustrated in Figure 11 and a collector layout plan illustrated in Figure 12 were prepared for the solar thermal system permitting process.

Figure 11: Location Layout Plan



Source: Treasury Wine Estates

Figure 12: Collector Layout Plan



Source: Treasury Wine Estates

ergSol's high-performance ETCs provide carbon-free heat energy to the industrial process. 240 collectors are mounted onto 30 arrays (frames), each comprising 8 collectors, to convert the sunlight into heat energy. ergSol developed a pre-fabricated module. Five collector banks, each with six collector arrays, are piped in a reverse return pattern to ensure consistent flow through each of these banks. Before shipment, all components were built, and pressure tested to ensure smooth component integration.

Evacuated Tube Collector

Collectors, which gather the sun's radiation, are a key element in all solar thermal applications. The mounted solar thermal collectors harness the free and readily available solar energy to heat the transfer fluid inside the collectors. The solar radiation is transformed into heat energy within the fluid, providing carbon-free heat energy to the ST system.

ergSol's high-performance ETCs represent localized, non-concentrating, non-tracking ST design. Each tube contains a metal absorber fin, harvesting up to 96 percent of the available solar resource. The fin is covered with a coating that absorbs solar energy highly efficient but inhibits radiative heat loss. Air is removed or evacuated from the glass tubes to form a vacuum, which mitigates conductive and convective heat loss. The absorber fin transfers the heat energy to the heat exchanger pipe, and the energy will be collected in the manifold. The collectors are usually made of parallel rows of transparent glass tubes. The evacuated tubes are equipped with a visual indicator to give the status of the vacuum. Those collectors can be installed flat/horizontally on roofs/grounds or vertically on the façade of a building. Since the absorber fin inside the tube is oriented to be precisely aligned with the sun, there is no need to tilt the collectors. Those collectors fit aesthetically into building exterior architecture designs due to their low profile and small footprint. Details of the ergSol collector 100-6df are illustrated in Figure 13.

Figure 13: ergSol Collector 100-6df



Source: ergSol, Inc.

Collectors in larger projects are frequently mounted on angled supports on flat roofs to be aligned at an optimal angle with the sun. When installing several rows of collectors, sufficient clearance needs to be considered to prevent shading. Determining this clearance requires the angle of the sun at midday on December 21, the shortest day of the year. The calculation procedure is specified in VDI 6002 Part 1 (VDI). The resulting clearance between rows is calculated as follows:

Equation:

$$\frac{z}{h} = \frac{\sin(180^\circ - (\alpha + \beta))}{\sin \beta}$$

Where

Z = Collector row clearance

H = Collector height

α = Collector angle of inclination

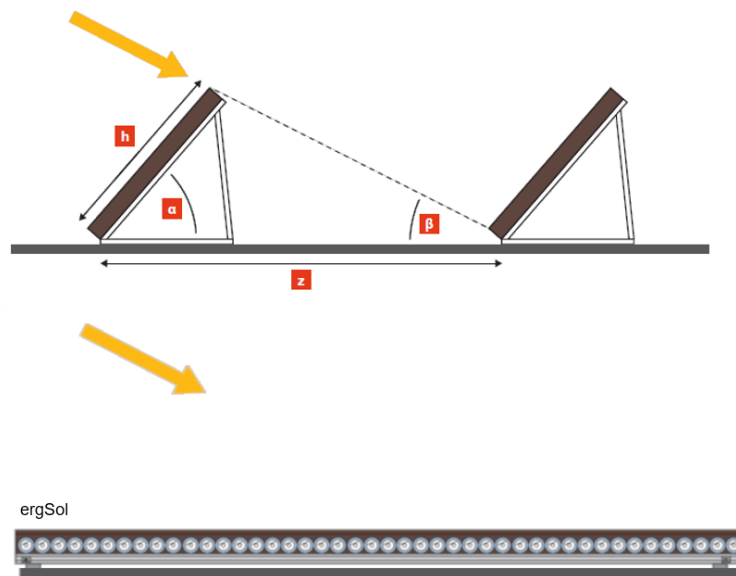
β = Angle of the sun

This is illustrated in Figure 14.

Evacuated tube technology is applicable in any climate zone, utilizing direct and diffuse sunlight. For this TWE project, the global annual irradiation accounts for 1,757 kWh/m², whereas the diffuse annual irradiation is 579 kWh/m².

ergSol's collector tube has been OG-100 certified by the U.S. Solar Ratings and Certification Corporation (SRCC) – the authoritative solar thermal performance rating organization for the U.S. market. Products are certified to the requirements of International and Uniform Codes and Standards with the intention of protecting and providing guidance to consumers, incentive providers, government, and the industry. ergSol collectors attained for collector performance SRCC Clear E = 4.039 kWh/m²/day and an efficiency of 92.8 percent based on absorber area. The collectors are certified under number 10001807.

Figure 14: Collector Characteristics



Source: ergSol, Inc.

ergSol collectors have minimal wind load. A Wind Tunnel Test and Load Analysis for the collector roof mount system has been completed, providing detailed information for structural engineers and permitting agencies. By knowing how wind and buildings interact, the design team can increase the efficient use of materials, reduce unnecessary costs and risks, and ensure a reliable design that is comfortable for occupants.

These collectors offer significant advantages and have considerable potential for industrial applications. They achieve high temperatures with high efficiency; they are made using high quality, corrosion, and UV-resistant materials; and are designed to produce a consistently high thermal output. The advanced, high-performance ETCs are being manufactured by ergSol in the U.S. The ability to produce affordable components domestically is notable in terms of economic value to California, including tax revenue and job creation. It will foster innovation and drive broad and sustained economic growth.

Hot Water Storage Tank

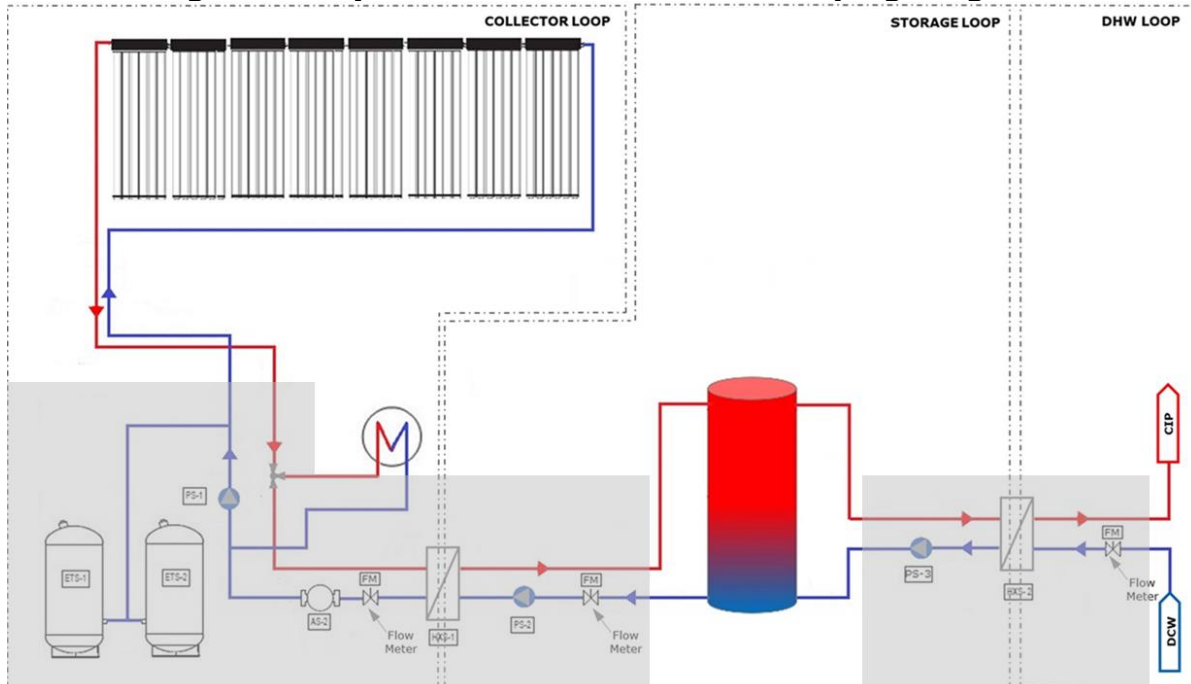
Heat storage provides advantages when there is a mismatch between thermal energy supply and energy demand. Solar heated water is stored as part of the system to extend the solar energy into the evening / early morning hours as well as for capturing the energy over the weekends, thereby increasing year-round energy and cost savings. A thermal energy atmospheric storage tank holding 10,000 gallons of water with an energy capacity of 3.5 MWh is integrated into this project's solar thermal system. The storage serves as a 24/7 energy manager, supplying the needed energy immediately and storing the rest for later use. Storage tank insulation and temperature stratification help minimize thermal losses from the ST system and increases thermal efficiency. Stratification refers to the thermal layering of water at different temperatures within the tank. Hot water from the solar collectors rises to the top of the tank due to a lower density. Hot water is discharged for consumption from the hottest part of the tank, while water from the coldest part of the tank will recirculate through the collector loop heat exchanger. A tall narrow diameter tank was selected for better stratification with a height of 339" and a 96" diameter.

The hot water storage tank is a carbon steel, atmospheric tank with spray-on polyurethane foam factory insulation with topcoat. The tank has a nominal R-value of R-16 at 2" thick. This exceeds ASHRAE requirements. The product is designed for use in applications where the stringent requirements for a Class I system must be met. Its physical properties result in exceptional fire resistance. R-16 foam outdoor tank insulation is an effective alternative to metal jacketed tanks at about 70 percent saving for the same R-Value.

Solar Thermal Pump Station

The pump station is used for moving the heat transfer fluid from the collectors to the solar storage tank, and from there to the point of interconnection to the existing boiler system, it works in conjunction with the solar controller to maintain consistently high efficiency. The pump station was prebuilt in a container and features a flexible modular design for easy maintenance access and installation efficiency. A diagram for instrumentation and piping is presented in Figure 15 with shaded parts related to the modular container installation.

Figure 15: System Instrumentation and Piping Diagram



Source: ergSol, Inc.

A list of major ST system components is shown in Table 2 to characterize the system and individual component performance.

Table 2: Relevant Solar Thermal System Components

Collector Loop	Specifications
Solar Thermal Collector Arrays	SRCC Certification 10001807
Expansion Vessels (2) (ETS-1, ETS-2)	Tank Volume: 264 gallons each Maximum Design Pressure: 150 PSI Temperature Range: -20°F to 240°F
Air Separator (AS-2)	Max. Working Pressure: 150 psi Temperature Range: 32°F – 270°F Efficiency: 100% removal to microbubble level
Flow Meter (FM-1)	Flow Range: 10.49...157.34 gpm Accuracy: $\pm 2\%$ of flow rate within flow range; $\pm 0.5\%$ repeatability Fluid Temperature: hot 40°F...260°F
Pump (PS-1)	Flow Rate: 39.2 gpm Liquid Temperature Range: 5°F...284°F
Heat Exchanger (HXS-1)	Plate and Frame HX Volume Flow: 8.90 m ³ /h Design Max Temperature: 230°F Design Max Pressure: 10.34 barg Heat Exchanged: 206,2523 Btu/h
Heat Dissipater	Heat Rejection: 10,152 Btu/min Coolant: Water GPM: 18.9
Storage Loop	Specifications
Solar Storage Tank (BTS)	Dimensions: height 339" ; diameter 96" Insulation: R-16 Volume: 10,000 gallons
Pump (PS-2)	Flow Rate: 39.2 gpm Liquid Temperature Range: 14°F...230°F
Pump (PS-3)	Flow Rate: 46.2 gpm Liquid Temperature Range: 14°F...230°F
Flow Meter (FM-2)	Flow Range: 10.49...157.34 gpm Accuracy: $\pm 2\%$ of flow rate within flow range; $\pm 0.5\%$ repeatability Fluid Temperature: hot 40°F...260°F
Heat Exchanger (HXS-2)	Plate and Frame HX Volume Flow: 10.60 m ³ /h Design Max Temperature: 230°F Design Max Pressure: 10.34 barg Heat Exchanged: 684,843 Btu/h
DHW Loop	Specifications
Flow Meter (FM-3)	Flow Range: 10.49...157.34 gpm Accuracy: $\pm 2\%$ of flow rate within flow range; $\pm 0.5\%$ repeatability Fluid Temperature: hot 40°F...260°F
Solar thermal system is being integrated into existing DHW	

Source: ergSol, Inc.

Energy from the sun heats the transfer fluid, water, as it flows via pump throughout the collector loop (closed-loop). Parts of the collector loop include an air separator (AS-2), a collector loop pump (PS-1), and a heat exchanger (HXS-1). The air separator purges the air out of the closed-loop to avoid corrosion. The pump circulates the heat transfer fluid through the system. The heat exchanger transfers the heat energy from the collector loop into the storage loop. The pump (PS-2) charges the storage tank (BST). The harvested energy is stored in the storage tank (BST). The storage tank is connected via the heat exchanger (HXS-2) to the application. The pump (PS-3) releases the energy on demand through this heat exchanger into the Domestic Hot Water loop, preheating the boiler feedwater for the production operation.

A solar collector generates heat whenever sunlight strikes the absorber, independent of the demand. If the heat cannot be transferred, the system switches off and goes into stagnation. Overheat protection is provided by the pressure management system (ETS), which will compensate for the volume change due to temperature change. It is sized following the operating state and manages the pressure changes for safety reasons. The expansion vessels equalize changes of fluid volume in the system, holding the heat transfer medium when there is a lack of demand. Following stagnation, the system returns to operation automatically. Pressure relief valves were integrated to avoid damages due to overpressure. An additional safety feature, a heat dissipater, was included to allow heat to be dissipated to the atmosphere, should the storage tank be fully charged, the collectors generating heat and no heat demand for the application is needed. The flowmeters FM-1, FM-2, and FM-3 were used for monitoring and measurement purposes. Temperature sensors are required for controlling the pump operations.

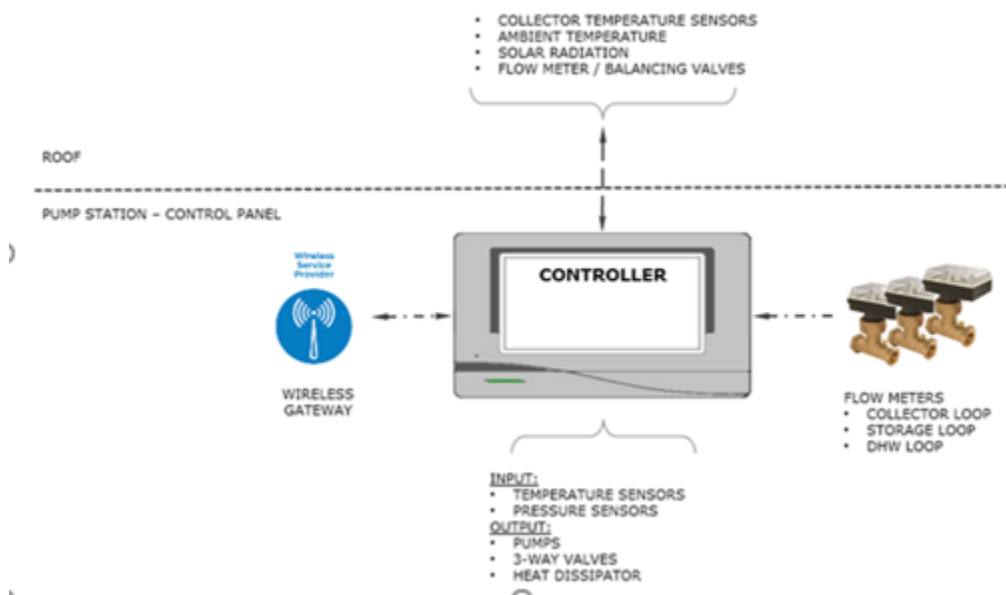
In the Sonoma area, ergSol recommended water as a heat transfer fluid since there are no permanent frost issues. Freeze protection is provided according to CSI guidelines. The heat transfer medium comprises water without antifreeze. The water will be circulated in the system to prevent the water from freezing. Pumps automatically switch on should the temperature drop below a specific temperature. Water as a transfer fluid provides many benefits: high heat capacity and conductivity allowing efficient heat transportation, non-toxicity and environmental-friendliness, low viscosity for easy pumping of the fluid, low cost, availability, and lower maintenance costs. Water is affordable, everywhere available, technically easy to control, environmentally friendly, and water has a high heat capacity – leading to better efficiency and lower maintenance costs.

The typical anti-freeze solution is a mixture of water and propylene glycol, but a water/ethylene glycol solution, silicon oil, hydrocarbon oil, or refrigerant could also be used. The common practice of solar system designs is to use a water/propylene glycol mixture to lower the freezing temperature. The mixing determines the lowest operating temperature. The main drawbacks are: reduced heat capacity while the viscosity is increased, reduction in efficiency, need for more pump energy, periodic fluid replacement/monitoring, and requires additional maintenance. In addition, the glycol molecules “crack” at higher temperatures during stagnation. They can then link up with other molecules, accelerating the formation of acids (risk of corrosion). If glycol is used, additional overheat protection must be used. The installation is monitored for energy performance. On-site/remote monitoring and control system run all aspects of the solar thermal system and can adapt to changing conditions. Operational stability will reduce labor costs for maintenance. To correctly measure and

evaluate the data, it is important to identify the points of measurements and the ways and means of collecting and storing the performance data of the solar thermal system. BTU data was calculated from three Badger BTU meters, which include flow and temperature sensors. The BTU meters were installed on the generation side (collector loop), the storage side (storage loop), and on the load side (DHW loop) of the system. Data was collected and recorded through a data logger.

Additional measurement devices were installed throughout the collector field on the roof, such as temperature sensors, solar radiation sensors, and flow meters. Throughout the pump station, other temperature and pressure sensors were installed to monitor and control the system. The programmed controller provided signals to various pumps, valves, and the heat dissipator to ensure that the system was operating properly. The system monitors whether certain conditions are satisfied, and the Operator will be notified by email (initiated by the controller) in the event certain conditions are not met. Data was collected, downloaded, archived in cloud storage, and analyzed. The monitoring system can be integrated via ModBus protocol into the host's process management system. Figure 16 provides details on the control diagram mapping.

Figure 16: Control Diagram Mapping



Source: ergSol, Inc.

The controller has a sequence of operations programmed to control the solar collector loop, the storage tank loop, and the process heat supply loop. In addition, there are safety programs that are included for freeze protection and high-temperature protection through the operation of a heat dissipator. For the solar collector loop, pump PS-1 is controlled to circulate water through the collectors when conditions are favorable for charging the storage tank. This is when the temperature at the collectors is higher than the top of the storage tank. For the storage tank loop, pump PS-2 is controlled to circulate water through the storage tank loop during similar conditions to when PS-1 is enabled. The three-way valve at the storage tank is controlled to maintain the thermocline in the storage tank and prevent the mixing of the hot and cold water in the storage tank. For the process load loop, pump PS-3 operates to provide hot water from the storage tank to the loop when hot water is needed for the CIP process. Freeze protection of the system is provided by operating the pumps to circulate water through

the loops as the water temperatures in the collectors, storage loop, and storage tank approach freezing. Overheating protection is provided by diverting collector loop transfer fluid through the heat dissipator. When the temperature of the water in the collectors and at the top of the tank approach boiling temperature, the three-way valve switches to pass water through the heat dissipator, which turns on and rejects heat until the fluid drops to a safe temperature.

Solar Thermal System Installation at Treasury Wine Estates

ergSol, Inc. partnered with Lloyd W. Aubry Company, Inc. for the demonstration project. Lloyd W. Aubry was instrumental in the successful turn-key installation of the solar thermal system, providing knowledge, expertise, integrity, high-quality job performance, and a high level of safety to the project implementation. They administered all contractual requirements, project activities, and managed all contractual responsibilities of work performed.

The installation began with a safety guardrail scaffolding system around the roof area impacted by the collector installation. Solar support aluminum rails were mounted onto the metal roof according to the structural layout plan and adjusted to compensate for potential uneven parts of the roof. On top of the rails, the solar thermal collector arrays were installed flush against the slightly sloped roof of the building. There is no need to tilt the collectors, and therefore, shading issues was not considered. The resulting installation area was reduced to a minimum. Collector installation was prepared and coordinated in an optimal way for safe and fast collector placement. Figure 17 shows images of the installed solar thermal collector field.

Figure 17: Solar Thermal Collector Field



Source: ergSol, Inc.

The collectors were manufactured and leak tested by ergSol before shipment. The solar collector arrays were plumbed in a reverse/return fashion to ensure constant flow throughout all the collectors. ergSol collectors require minimal maintenance or attention during normal operations. The installation was monitored for energy performance. On-site/remote monitoring and control system run all aspects of the solar thermal system and can adapt to changing conditions. Operational stability reduced labor costs for maintenance.

A 10,000-gallon storage tank with an energy capacity of 3.5MWh was installed adjacent to the building, as well as the containerized pump station for the solar thermal system. The water tank was anchored at 18 equally spaced locations on a 6.83ft diameter. The storage tank water is filled once during commissioning and is circulated between the storage tank and the solar collector loop heat exchanger. The heat from the solar collectors is transferred to the storage tank and heats up the water in the tank. The heated water is pumped through a second heat exchanger, depending on the DHW demand. Both heat exchangers are external to the tank: stainless-steel plate heat exchangers, which ensure optimum water - hygienic properties. External heat exchangers are chosen due to maintenance benefits.

Eight 3 ft tall pedestals support the containerized pump station in a 20ft container. A crane was used to set the tank and container. Figure 18 shows the foundation site work for the tank and container and its completion. The hot water from the tank is piped to the existing hot water units, providing thermal energy to the company's operation as needed. All stainless-steel piping is welded and insulated.

Figure 18: Tank and Container Installation



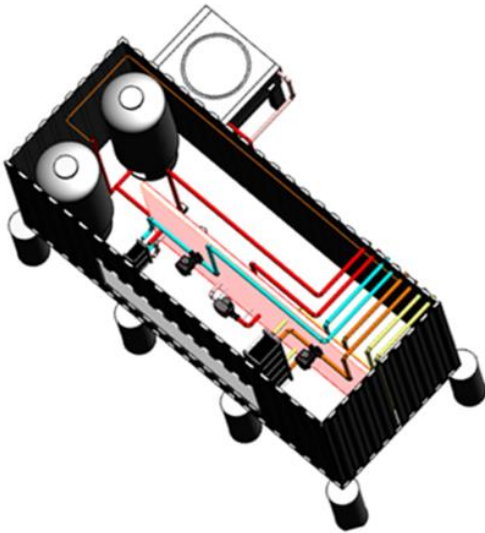
Source: ergSol, Inc.

The pump station is used for moving the heat transfer fluid from the collectors to the solar storage tank, and from there to the point of interconnection to the existing boiler system, the station works in conjunction with the solar controller to maintain consistently high efficiency.

The pump station is a prebuilt modular flexible design in a 20 ft container with the following dimensions: height 102", length 238½", width 96". Mechanical and electrical components such as measurement devices, flow meters, temperature sensors, pressure sensors, pumps, heat exchangers, expansion tanks, and controllers have been assembled into a kit at ergSol's facility and delivered to the site. Sufficient measurement points allow for the identification of operation and calculation of efficiency. All copper plumbing components in the container are assembled using ProPress fittings. The use of pre-assembled, pre-designed component groups, standardized configurations, and components allow for easy access for maintenance and installation efficiency.

However, just as viable, the container is for the operation, the innovative design presents the aesthetic sophistication of the project as well. The customized solar thermal pump station in a contained space highlights the engineering aspects of the solar thermal pump station. The minimum distance between the main components of the solar thermal system, such as the collector field, storage tank, solar thermal pump station, and short pipe lengths, affects the efficiency of the system. Further value is added by providing visitors to the winery easy access to the project and by visually displaying the company's engagement in energy efficiency efforts and environmental sustainability. Figure 19 provides details on the containerized pump station design.

Figure 19: Containerized Pump Station Design



Source: ergSol, Inc.

Figure 20 shows the installed integrated solar thermal system comprised of the collector field, storage tank, and pump station.

Figure 20: Integrated Solar Thermal System



Source: ergSol, Inc.

CHAPTER 3:

Project Results

Measurement and Verification Approach

Enpowered Solutions LLC provided Commissioning, Measurement and Verification (M&V) services, as well as energy consulting during the design, construction, and closeout phases. M&V is an estimation of the realized energy savings due to the impacts of the project. For this project, resource savings are defined as reductions in energy usage, whereas cost savings are reductions in the cost of energy. Energy savings during the M&V period are calculated by monitoring the amount of energy produced by the solar thermal system and used by the CIP process, using the metering equipment added during the installation.

The M&V methodology approach and process used is outlined in the "International Performance Measurement and Verification Protocol" (IPMVP). The IPMVP protocols are an HVAC industry standard for performing measurement and verification on energy efficiency projects and provides guidance for measuring, computing, and reporting savings. The protocols are developed by the Efficiency Valuation Organization, which is a coalition of international organizations, led by the US Department of Energy. Examples of major programs that require these guidelines to be followed for measurement and verification include LEED and the Federal Energy Management Program. Specifically, to evaluate the impact on the natural gas utility consumption, Option B - Energy Conservation Measure (ECM) Isolation was employed (details in Reference Section).

The Option B – ECM Isolation approach is best suited for this solar thermal installation project because the performance of the system can be easily isolated, and there are insignificant interactive effects with other building equipment. The following are the reasons why the use of IPMVP M&V Option B is preferred for this project:

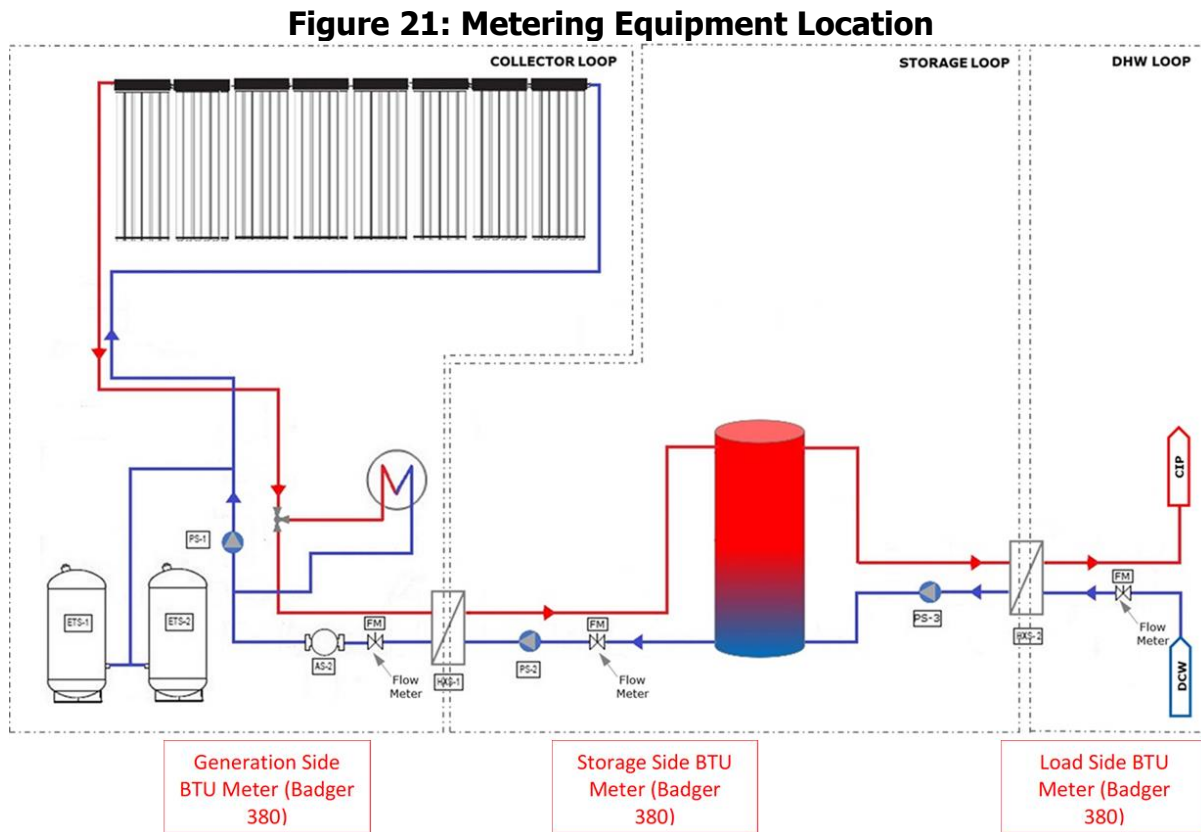
- Performance is only the energy produced by the solar thermal installation.
- Interactive effects with other systems are insignificant.
- Parameters that affect energy use are easy to monitor.
- Meters can be used for operational feedback of the system.

To correctly assess the energy savings, sources of the energy generated by the new system were identified, and the assessment was limited to those systems. This assessment process is called the 'savings boundary,' since any changes, whether positive or negative, outside of this 'boundary' are not attributable to this project. The M&V period began once the system was commissioned. Adjustments and fine-tuning of the system was still in progress during the first few weeks of data measurement.

Three BTU meters: Badger Meter Series 380 Impeller BTU system (includes flow and temperature sensors), with ± 2 percent accuracy, were installed on:

- Generation Side (Collector Loop)
- Storage Side (Storage Loop)
- Load Side – CIP Process (DHW Loop)

Figure 21 - shows where the metering equipment is installed.



Source: ergSol, Inc.

Data Analysis

For the solar thermal system design, Polysun software was used to size the system and estimate annual performance. The initial performance by the Polysun model used a boiler efficiency of 82 percent, a modeling assumption from the California Solar Initiative Thermal Program. The initial performance estimate based on simulation (Table 3) of the solar thermal installation shows an expected savings of 13,200 therms/year, annual generation of 1,084 MMBtu/year, and avoided costs of \$12,144 based on NG costs of \$0.92/therm.

Table 3: Initial Simulation Predicted Performance Estimate

	Annual Generation (MMBtu/yr)	Offset Natural Gas Savings(therms/yr)	Avoided Costs (\$/yr)
Initial Simulation (boiler efficiency 82%)	1,084	13,200	\$12,144

Source: ergSol, Inc.

Once the design progressed, the performance was updated to use a 96 percent boiler efficiency to match the nameplate data of the existing boiler and was used as the basis for the M&V expectations. The estimated energy baseline is shown in Table 4.

Table 4: Estimated Energy Baseline

	Annual Generation (MMBtu/yr)	Offset Natural Gas Savings(therms/yr)	Avoided Costs (\$/yr)
Expected Results (boiler efficiency 96%)	1,084	11,291	\$10,387

Source: ergSol, Inc./Enpowered Solutions

Data from the three BTU meters, on the Generation Side, Storage Side, and Load Side was collected from February 7, 2020, to March 13, 2020, at 30-second intervals for this M&V Report. Data for each BTU meter includes flow, supply temperature, return temperature, and cumulative energy.

The interval data from the data logger for the CIP process BTU meter, including flow, supply, and return water temperatures, was used to calculate the hourly load delivered to the CIP process from the solar thermal system. An average weekly profile of energy delivered to the CIP process was developed from the five weeks of data collected. This data was then extrapolated to an annual usage by multiplying by the number of weeks TWE operates, with holidays subtracted. To calculate the reduction of the natural gas usage from the boilers, due to the heating load reduction from the solar thermal system, the energy provided by the solar thermal system was divided by the boiler efficiencies. The formulas used for this analysis are:

$$\text{Energy (Btu)} = \text{Average Weekly Energy to CIP Process (Btu/week)} * (\# \text{ weeks of TWE operation})$$

Where

$$\# \text{ weeks of TWE operation} = 52 - (\text{number of holidays} / 7)$$

The natural gas savings is calculated by the following formula:

$$\text{Natural Gas Savings (therms)} = \text{Energy (Btu)} / \eta_{\text{boilers}} / 100,000 \text{ (Btu/therm)}$$

where

$$\eta_{\text{boilers}}: \text{efficiency of the existing boilers} = 96 \text{ percent}$$

Table 5 shows the resulting energy data from actual operation in February and March (low solar azimuth) extrapolated out for a full year operation without taking into account seasonal solar generation variation.

Table 5: Extrapolated Energy Data based on Measurements

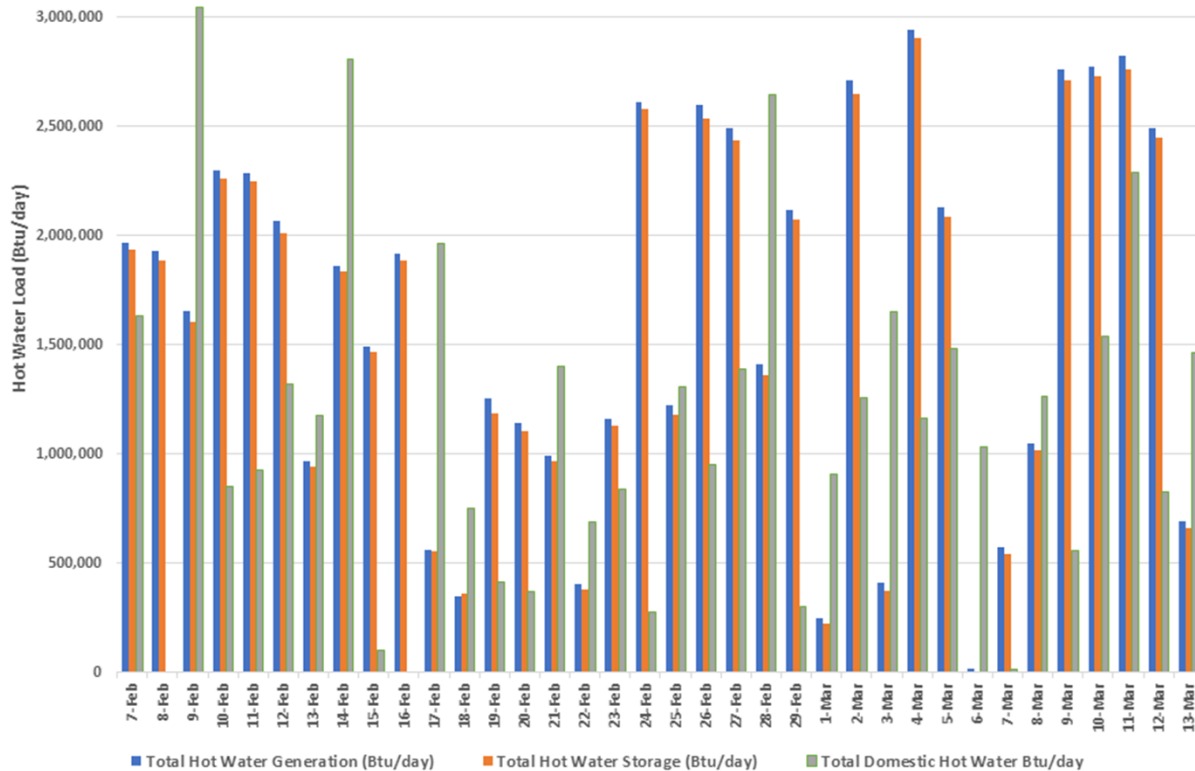
	Annual Generation (MMBtu/yr)	Offset Natural Gas Savings(therms/yr)	Avoided Costs (\$/yr)
Installed System Performance	583	4,081	\$3,754

Source: ergSol, Inc./Enpowered Solutions

The M&V period began once the system was commissioned. Adjustments and fine-tuning of the system were still in progress during the first few weeks of data measurement. Data from the data logger was collected and analyzed to assess the annual performance of the solar

thermal system. The numbers are based on five-weeks of 30-second data collected from February through March, which corresponds to the lowest generation time of year. The analysis shows that the generation and storage from the solar system is greater than the domestic water use (Figure 22).

Figure 22: Daily Hot Water System Loads (Generation, Storage, and CIP)



Source: ergSol, Inc./Enpowered Solutions

For the analysis, the first assumption is the solar thermal system generation, and storage will be larger than the process (CIP) usage for all times of the year. The M&V data period is taken during winter months when the solar thermal generation production is at its lowest, and it was shown that the thermal generation was still greater than the process usage.

The second assumption used in the M&V analysis is the CIP process schedule, and the load remains consistent throughout the year, with the following schedule, as provided by TWE:

- Monday to Thursday: 3,900 gallons/day, for Quick CIP and Cellar Tank Sanitation processes
- Friday: 9,500 gallons/day, for Full CIP and Cellar Tank Sanitation processes
- Saturday, Sunday, and Holidays: 0 gallons/day.

The difference between extrapolated energy data based on measurements and expected solar thermal generation is discussed in more detail in the results section.

Results

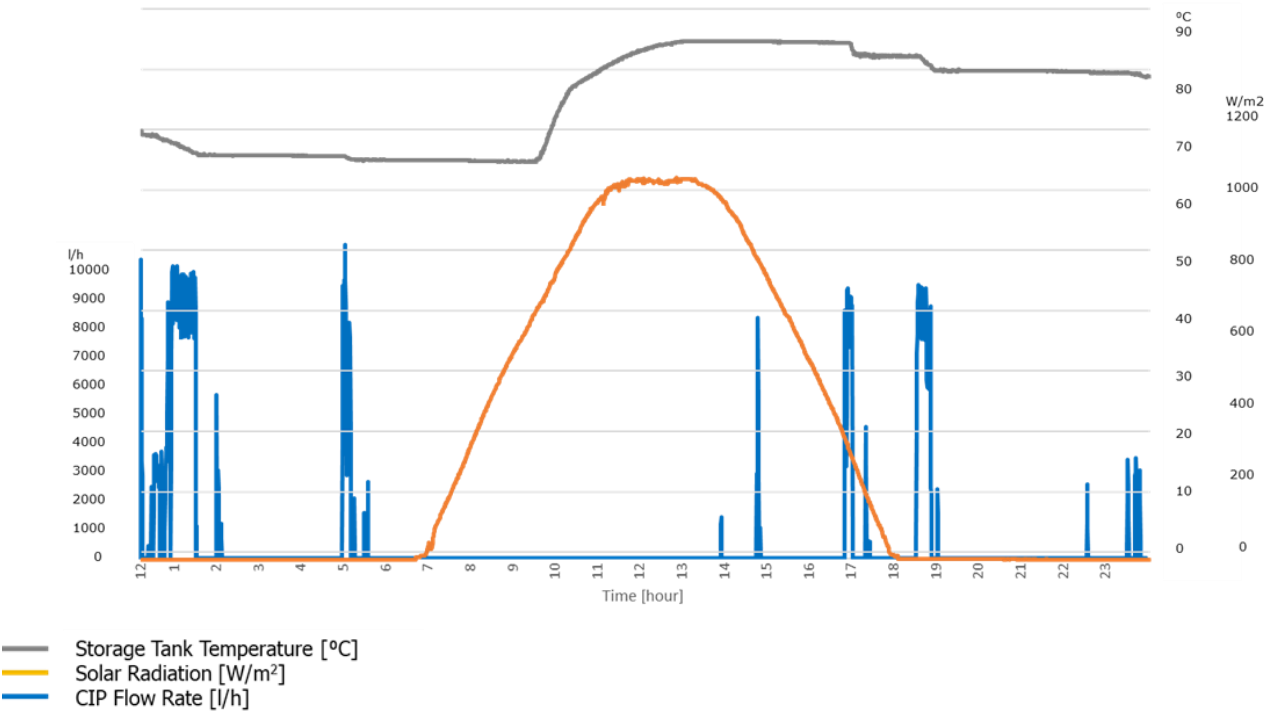
The solar thermal system installed at TWE consists of 240 evacuated tube collectors with 4,106 sq.ft. gross area. The thermal energy generated by the solar thermal system is used to

pre-heat hot water used in the company’s CIP system to clean the bottling lines and sanitize cellar tanks.

Comparing the installed system performance with the expected results, the installed system is estimated to produce 54 percent of the expected annual generation and to offset 36 percent of the expected natural gas use. The offset natural gas is calculated by how much thermal energy is transferred to the CIP process water. This is dependent on how much water is being used by the TWE process. The offset natural gas use is extrapolated from the actual CIP use for the same time period, which is using 69 percent of the solar thermal energy generated during the trend period. It is recommended that another measurement and verification analysis be conducted in autumn, to analyze the system performance from the summer months and take into account any potential variations in the process water usage schedule. Additionally, it is recommended that TWE analyze the current CIP process with the water use estimated to size the solar thermal system and see if the CIP water use can be optimized to fully use the production from the solar thermal system.

The following trend data reflects the importance of a storage tank for balancing the fluctuations in timing between the availability of insulation and the demand for heat. The solar radiation started shortly before 7.00 AM, increased until about 11.00 AM, and the declination started at about 1.30 PM, reaching a maximum of 1,100 W/m². The storage tank was charged by 20 Kelvin (K) (65°C to 85°C/149°F to 185°F) during the day. The period of heat generation and the period of heat consumption are rarely the same. This highlights that for a successful operation of solar thermal systems, an adequately sized thermal energy storage is essential for providing on-demand heat energy for the industrial operation (Figure 23).

Figure 23: Trend Data for March 11, 2020



Source: ergSol, Inc.

The thermal performance of solar water heating is typically described in terms of a solar fraction (SF), which is defined as the percentage of the hot water load that can be met by solar energy on an annual basis. The equations for SF are shown as:

Equation 1:

$$E_{\text{Solar}} = 500 \times \frac{dV}{dt} \times \frac{d(\Delta T)}{dt}$$

Where

E_{Solar} = Energy provided by the solar thermal system [BTU]

T = Temperature [$^{\circ}\text{F}$]

ΔT = $T_{\text{supply}} - T_{\text{return}}$ [$^{\circ}\text{R}$]

V = Volume [gal]

500 = The BTU multiplier in the formula is 500. Because BTUs are measured per hour, the 500 comes from one gallon of water that weighs 8.33 pounds, times 60 minutes in one hour. (8.33 pounds X 60 minutes = 500)

Equation 2:

$$E_{\text{CIP}} = 500 \times \frac{dV}{dt} \times \frac{d(\Delta T)}{dt}$$

Where

E_{CIP} = Energy needed by the CIP system [BTU]

Equation 3:

$$\text{SF} = E_{\text{Solar}} / E_{\text{CIP}}$$

In these equations, E_{Solar} is the amount of energy saved by using the solar water heating system instead of a conventional water heating system on an annual basis. E_{CIP} is the amount of annual energy that would be needed to meet the water heating load assuming a solar water heating system is not installed.

The solar fraction calculated based on measured data from March 11, 2020 was 48.9 percent, a day within the lowest solar generation time of year. The energy provided by the solar thermal system (E_{Solar}) was 2.31 MMBTU, energy needed by the CIP system (E_{CIP}) was 4.73 MMBTU, resulting in the solar fraction (SF) for this particular day. The Polysun simulation showed an average SF of 57 percent for the month of March, increasing up to a SF of 80 percent in July, resulting in an average SF of 62 percent over the year.

The deviation between the extrapolated energy data based on measurements (Table 5) and the estimated energy baseline (Table 4) was affected by the seasonal circumstances. The performance during the M&V period of February through early March corresponds to the lowest solar generation time of year. The solar generation is expected to increase in the summer, which will increase the amount of heat transferred to the process water due to greater temperature differential between the solar hot water and the process water. In addition to the thermal energy generation, the offset natural gas is calculated by how much thermal energy is transferred to the CIP process water, which depends on how much water is

being used. The lower savings resulted due to lower domestic hot water usage across the plant, directly related to the plant production capacity.

While there were real operating conditions significantly impacting the estimated energy baseline, the findings indicate that the ISTS is capable of delivering the expected performance with the water usage estimated to size the solar thermal system throughout the year. Furthermore, the ISTS has the capability to deliver the initial predicted performance of 11,291 therms a year.

Warranty and Maintenance

According to the CSI Thermal Program, all contractor-installed systems must provide for the following warranties:

- All solar collectors must have a minimum of a 10-year manufacturer's performance warranty to protect against defects and a 15 percent performance degradation.
- All systems must have a minimum 10-year performance warranty to protect the purchaser against more than a 15 percent degradation of system performance over the 10-year period that may occur as a result of faulty installation.
- All systems must have a minimum 1-year warranty on installation labor and workmanship not otherwise covered by the manufacturer's performance warranty.

ergSol placed emphasis on designing the system to lower maintenance costs. ergSol's collectors require minimal maintenance or attention during normal operations. Glass tubes require no reflectors, and therefore less cleaning, and allow rain to filter through to the ground. The glazing may need to be occasionally rinsed in dry, dusty climates where rainwater does not provide natural rinse; this is not an anticipated need given the project's location. The evacuated tubes are equipped with a visual indicator to give the status of the vacuum. A getter is used to maintain the vacuum inside. During the manufacturing of the evacuated tubes, the getter is inductively exposed to high temperatures. This causes the bottom of the evacuated tube to be coated with a pure layer of barium. This barium layer eliminates any carbon monoxide, carbon dioxide, nitrogen, oxygen, water, and hydrogen outgassed from the evacuated tube during storage and operation. The barium layer also provides a clear visual indicator of the vacuum status. The silver-colored barium layer will turn white if the vacuum is ever lost. This makes it easy to determine whether or not a tube is in good condition. Should a tube malfunction, it can be easily replaced. The passive design requires no mechanical systems (for example tracking system).

Economic Analysis

To assess the impact on the costs of the heat produced by the solar thermal system compared to a conventional heating system, different scenarios were considered over 30 years. Data used for the calculations are based on numerous assessments provided for potential customers under non-disclosure agreements. The different scenarios are as follows:

1. For an existing conventional boiler system, it is assumed that the boiler will need to be replaced once (NREL 2014), the natural gas costs are \$0.92/therm with an annual consumption of 29,000 therms.

2. For an existing conventional boiler system, it is assumed that the boiler will need to be replaced once (NREL 2014), and the energy source will be renewable natural gas (RNG) at an assumed cost of \$2.63/therm with an annual consumption of 29,000 therms.
3. For an integrated solar thermal system (annual savings of 13,200 therms) in an industrial setting, where it is expected that cost reductions can be reached and federal tax and depreciation benefits can be used.
4. For the actual installation costs of the one-off CEC funded project demonstration system with annual savings of 11,291 therms.

The equation for the calculation of the levelized costs of heat is shown below:

Equation:

$$LCOH = \frac{I_0 + \sum_{t=1}^T C_t}{\sum_{t=1}^T E_t}$$

Where

- LCOH = Levelized Cost of Heat [\$/therm]
 I_0 = Investment Costs [\$]
 C = Operating and Maintenance (O&M) costs (\$)
 E = Thermal Energy Saved/Consumed [therm]
 T = Time [year]

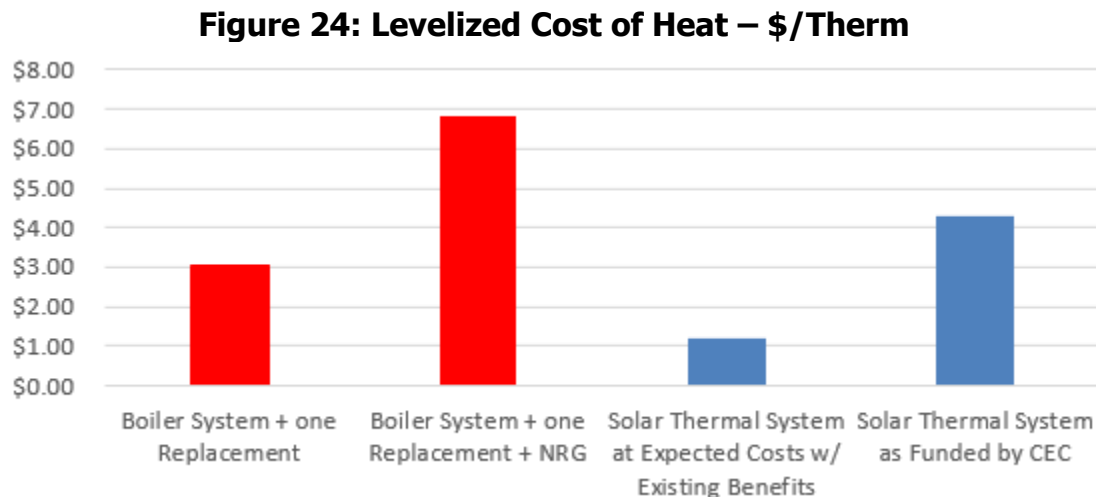
The various scenarios are outlined in Table 6. While the cost of an integrated solar thermal system is higher than for a gas boiler system, the operational expenses of a solar thermal system are typically much lower, given that the fuel (sunlight) is free. Any rises in industrial natural gas price will have a significant economic impact for companies and industrial units who have high NG consumption for process heat. Solar thermal can provide long-term hedging against fuel price volatility.

Table 6: Levelized Cost of Heat – Details on Various Scenarios

Category	Boiler System + one Replacement NG Cost \$0.92/therm	Boiler System + one Replacement RNG Cost \$2.63/therm	Solar Thermal System at Expected Costs w/ Existing Benefits	Solar Thermal System as Funded by CEC
CAPEX				
System Installed Price	\$188,000	\$188,000	\$862,468	\$1,363,283
Boiler Replacement	\$390,838	\$390,838		
Federal Tax Credit and Depreciation			\$482,743	
Investment Cost	\$578,838	\$578,838	\$379,725	\$1,363,283
O&M Costs (30 Years)	\$2,072,458	\$5,367,161	\$87,520	\$87,520
Total Costs over 30 years	\$2,651,297	\$5,945,999	\$467,245	\$1,450,803
Levelized Cost of Heat (\$/therm)	\$3.05	\$6.83	\$1.18	\$4.28

Source: ergSol, Inc.

Figure 24 summarizes the levelized costs for heat in \$/therm for the four scenarios previously described.



Source: ergSol, Inc.

The high costs for the solar thermal system funded by CEC (\$6.23/therm) were partly caused by the challenges encountered during the project. The estimated levelized cost of heat for similar installations is \$1.60/therm, assuming cost reductions through federal tax and depreciation benefits. Overall integrated solar thermal system costs are sensitive to context: climate, hot water demand, ST system size, design, and engineering expenses, system performance, cost of conventional fuels, and rate structures, costs of system components, site preparation costs, installer productivity and labor rates, project overhead rates (vary by market sectors), permitting, commissioning and other regulatory costs, supply chain costs, investment- or production-based incentives, tax or energy credits, and overall financial contracts. Localized integrated solar thermal systems can be a viable means for reducing the operation and maintenance costs over traditional boiler systems as documented in the 30-year cost analysis.

Beyond the direct economics on purely localized gas savings at a customer site, the positive economic impact on a state level should be considered if industrial solar thermal systems would be used more widely. California has to purchase 91 percent of natural gas that it uses from other states and Canada, sending nearly \$9 billion per year out of state (Levin et. al. 2014). Additional losses to California's economy include:

- Jobs
- Economic development
- Tax revenues
- Economic multiplier
- Public health impacts
- Environmental impacts

CHAPTER 4:

Technology/Knowledge/Market Transfer Activities

Solar Thermal Application Potential

The project goal was to demonstrate the technical and economic feasibility of a commercial-scale integrated ST system to generate on-demand thermal energy for industrial processes, displacing part of the NG use. The technology's applications are not limited to food processing and, once commercialized, can provide clean and cost-effective solar energy for various customers in any climate zone.

This project aimed to provide real-world data on the technical and economic feasibility, reliability, and durability of ST systems. The results could help overcome the primary obstacle to wide-scale deployment: customers will only invest in projects that use technology with a history of proven performance and are cost-effective. The data and results from this demonstration could help reduce the amount of risk for customers operating and financing this technology. Supporting data could provide a foundational justification for future utility rebate/incentive programs, energy codes/standards, securing private capital, and other funding to develop and improve the technology.

The ergSol ISTS can be customized to the end-users needs, such as versatile applications, temperature settings, and size. The pump station features a flexible modular design affording easy access for maintenance and installation efficiency. This research assessed the performance and validated the viability of the technology as a localized, energy-efficient measure for an industrial operation. The project could increase market acceptance and penetration, due to the system's replicability and scalability to other plants in similar settings across California and elsewhere. Long-term reductions in facility operating costs, GHG emissions reductions, reduced fossil fuel consumption, and a positive environmental impact are all important factors while remaining a competitive choice in the marketplace.

ergSol's highly efficient collectors capture the sun's natural energy to deliver safe, reliable, economical, clean energy for a wide range of industrial and commercial uses, including applications for

- Process Heating
- Cooling & Refrigeration (natural refrigerants)
- Water Treatment
- Desalination
- Domestic Water Heating
- Space Heating and Cooling
- District Heating and Cooling

Typical applications and the most promising industry sectors suitable for ST systems include food and beverage; dairy, poultry, and agricultural products; pharmaceutical industry; textile industry; paper industry; and metal surface treatment. All of these rely fundamentally on pre-

heated water for boilers, air conditioning, sanitation treatment, and other heat demanding processes.

Technology Integration

Solar Thermal technology is an under-used renewable resource, and optimization of these technologies for maximizing energy efficiency and decreasing GHG emissions for industrial and commercial applications (buildings and manufacturing processes) has scarcely been addressed. Localized applications are a valid and viable means of reducing the need for conventional primary energy sources. These benefits are not realized primarily due to:

- Lack of familiarity about the value of these systems for various industries.
- Lack of performance and cost data.
- Lack of mechanisms for ETC technology participation in the electricity and energy efficiency programs, in particular, due to the cross-cutting benefits of ST applications and resulting efficiency.
- Lack of project financing structures for this technology.
- Low natural gas prices impacting the cash flow from savings.

An effort should be made to provide incentives for solar thermal integration for industrial applications to increase the number and variety of ST technology demonstrations. If the industry is to be sustained, workforce training and development for industrial and commercial solar thermal integration should be expanded in the state's community colleges and universities.

Interdisciplinary collaboration is very critical to disseminate the information learned from the project effectively. Its outcomes should be communicated to multiple audiences to accelerate the deployment of advanced ISTSs for diversified applications in the industrial sector.

Prior to being awarded for the CEC grant, ergSol reached out to various audiences to create awareness about solar thermal integration potentials to meet the State's energy and GHG emission goals. Stakeholders included:

- Academia, Air Quality Management Districts, California Air Resources Board, California Energy Commission, Workforce Development Agency, and Small Business Administration
- Food processors, real-estate developers, architects, mechanical and structural engineering firms, construction companies, plumbers, HVAC contractors, installers, electricians, roofer, building inspectors, building commissioners, welders, insulators, vendors for solar thermal components, facilities and building operators, and various service providers.

A key component of technology transfer will be in the meticulous collection and analysis of information from the demonstration project. Communication tools will include fact sheets, journal articles, social media, press releases, and participation in conferences. ergSol will ensure that critical project delivery infrastructure is in place to meet expected market demand.

Market Transfer Activities

Throughout the course of the project, ergSol held multiple meetings with the Technical Advisory Committee members to discuss the scope of the project and requesting recommendations for technology transfer/information dissemination. ergSol reached out to various audiences to create awareness about solar thermal integration potentials to meet the State's energy and GHG emission goals.

Those activities included:

- TWE Internal News Article in March 2020: Sonoma Bottling Center's Commitment to Energy Management.
- TWE will be exploring the use of solar thermal across their business. The technology has several uses that could benefit the supply chain for TWE.
- Press Release: ergSol is among the 76 turnkey Solar Heat for Industrial Processes (SHIP) suppliers listed on the SHIP Supplier World Map on <https://www.solar-payback.com/suppliers/>.
- Conference Attendance: International Solar Energy Society (ISES) Solar World Congress (SWC) 2019 (<https://www.ises.org>), Food Processing Expo 2020 (www.foodprocessingexpo.org)
- Actively participating in various networks with other organizations, such as suppliers, competitors, contractors, sub-contractors, universities, utilities, governments, and professional associations.
- Activities with Food Processors: ergSol is currently working with two different food processors on the implementation of a cutting-edge hybrid system based on carbon-free solar thermal heat for heating and cooling needs for their processes.
- Planned Public Relations event at Treasury Wine Estates in Sonoma where various stakeholders and media would have been invited got postponed given the COVID-19 circumstances.
- Upon completion of the project study's Final Report, and with the approval from the CEC, the Final Report will be uploaded to ergSol's website for public dissemination. The report will also be posted on the CEC website.

The team developed a technology transfer plan and dissemination strategy to communicate directly with the food processing industry, as well as other industries, educational institutions, regulators, legislators, community organizations, the general public, and media about the potential to adopt the integrated ST approach. The combination of varied expertise in the project team, such as economic analysis, design, simulation, engineering, equipment production, installation, data collection, and monitoring, provides a comprehensive study for other industries with similar demands. ergSol's ISTS design and project learnings offer a cost-effective and energy-efficient strategy which may serve as the gridline for future use in related industries.

Just as the solar photovoltaic industry successfully faced a similar set of barriers a decade ago, the solar-enhanced thermal solutions business must also achieve a combination of milestones including technology validation, customer acceptance, component cost reductions, project financing, and establishment of a scalable installer infrastructure. The project aims to contribute to the development pathway.

CHAPTER 5:

Conclusions and Recommendations

Using and integrating localized ST technologies for industries with high thermal energy demand is a viable and sustainable solution for meeting California's carbon reduction goals as well as decreasing the need for conventional primary energy sources (fossil fuels) for industries. California's food processing industry is the third-largest industrial energy user in the state, with thermal energy demands of up to 80 percent of their total energy consumption. This industry represents a well-focused market segment for solar thermal applications. TWE's management team expressed interest in adding an innovative solar thermal system to their renewable energy resource portfolio. ergSol, along with its partners Lloyd W. Aubry Company, Inc., Empowered Solutions LLC, UC Davis Department of Viticulture & Enology, integrated a commercial-scale solar thermal system to generate localized, on-demand thermal energy for their existing operations.

ergSol's integrated solar thermal system was installed at TWE's Bottling Center in Sonoma to demonstrate the technical and economic feasibility of such a system for displacing part of their natural gas usage. The thermal energy generated by the solar thermal system is used to pre-heat water used in the CIP system to clean the bottling lines and sanitize cellar tanks. The ISTS has been continuously operating to meet the hot water demand of the CIP process.

ergSol designed and manufactured an innovative, highly-efficient ISTS with high-performing ETCs that consists of 240 evacuated tube collectors with 4,106 sq.ft. gross area, a 10,000 gallon storage tank with an energy capacity of 3.5MWh, and a flexible modular design for the pump station. ergSol's collectors are made of single-walled glass tubes that contain a metal absorber fin. Those collectors can provide more than 300°F temperature heat with high efficiency, making them appropriate for industrial process heat needs. They are installed flush against a slightly sloped roof of a building. A thermal energy storage tank was integrated into the design to extend the solar energy into the evening/early morning hours as well as for capturing the energy over the weekend, thereby increasing year-round energy and cost savings. The pump station is used for moving the heat transfer fluid from the collectors to the solar storage tank, and from there to the point of interconnection to the existing boiler system, it works in conjunction with the solar controller to maintain consistently high efficiency. The pump station was prebuilt in a container and features a flexible modular design for easy maintenance access and installation efficiency.

Equally impressive is the aesthetic sophistication of the project. The container's innovative design highlights the engineering aspects of the solar thermal pump station. The minimum distance between the main components of the solar thermal system, such as the collector field, storage tank, solar thermal pump station, and short pipe lengths, increases the overall efficiency of the system. Further value is added by providing visitors to the winery easy access to the project and by visually displaying the company's engagement in energy efficiency efforts and environmental sustainability. It highlights the ways in which the company is delivering on its commitment to being sustainable.

After commissioning the system, adjustments and fine-tuning of the system were performed, and it has operated with reliability and safety since its commissioning. The five-week M&V

analysis showed a deviation between the extrapolated energy data based on measurements and the estimated energy baseline affected by the seasonal circumstances. The performance during the M&V period of February through early March corresponds to the lowest solar generation time of year. The solar generation is expected to increase in the summer, which will increase the amount of heat transferred to the process water due to greater temperature differential between the solar hot water and the process water. In addition to the thermal energy generation, the offset natural gas is calculated by how much thermal energy is transferred to the CIP process water, which depends on how much water is being used. The lower savings resulted due to lower domestic hot water usage across the plant, directly related to the plant production capacity.

While there were real operating conditions significantly impacting the estimated energy baseline, the findings indicate that the ISTS is capable of delivering the expected performance with the water use estimated to size the solar thermal system throughout the year. Furthermore, it is presumed that the ISTS has the capacity to deliver the initial simulation predicted performance of 13,200 therms/year and approximately 70.2 metric tons/year CO₂ emission reductions and \$12,144/year in savings, based on CEC data (CEC 2016). Despite the necessary end of the contracting period, ongoing performance data will be collected and is provided after Chapter 6. The deviation between the extrapolated energy data based on measurements and the estimated energy baseline was affected by the seasonal circumstances. The performance during the M&V period of February through early March corresponds to the lowest solar generation time of year. The solar generation is expected to increase in the summer, which will increase the amount of heat transferred to the process water due to greater temperature differential between the solar hot water and the process water. In addition to the thermal energy generation, the offset natural gas is calculated by how much thermal energy is transferred to the CIP process water, which depends on how much water is being used. The lower savings resulted due to lower domestic hot water usage across the plant, directly related to the plant production capacity.

The estimated levelized cost of heat for the TWE project is estimated to be \$4.28/therm as documented in the 30-year cost analysis. However, the estimated levelized cost of heat for similar installations is \$1.18/therm, being competitive with natural gas systems and very attractive against a potential rise in gas prices.

CHAPTER 6:

Benefits to Ratepayers

Solar thermal technology is an under-used renewable resource, and optimization of ST technologies for maximizing energy efficiency for industrial and commercial applications (buildings and processes) has scarcely been addressed. Localized ST applications could be a valid and viable means for reducing the need for conventional primary energy sources. ST systems are particularly suited to support the integration of energy efficiency in industrial processes as well as in buildings to supplement on-site demand for thermal loads. This will help meet California's aggressive energy efficiency and greenhouse gas reduction goals.

The California food processing industry is one of the target markets for solar thermal applications. Energy, safety and security, global competition, water, regulations, and labor costs are some factors of concern for this industry. Energy — quality, reliability, and cost — is essential in retaining and growing the food processing industry in California. Those businesses can be most affected by high energy costs, price fluctuations, and even by interruptions in utility services that can have significant effects on the cost and safety of the products.

Reducing energy needs for food processors through effective implementation of localized solar thermal technology will offer *food processors* opportunities for

- Increased efficiency
- Immediate reduction of energy costs
- Long-term operational cost-effectiveness
- Energy storage
- Reliability of energy
- Competitive advantages

Reducing the energy needs provides benefits to the greater economy, environment, security: Implementing highly efficient ISTSs may contribute multiple benefits to California's natural gas ratepayers. The findings of this demonstration project will be shared with various stakeholders, not limited to food processors. They will serve as a model to adapt to their circumstances to improve production efficiencies and enhance the competitiveness of the industry in California.

Economic benefits can also apply to the surrounding communities in the form of

- Lower energy costs
- Long-term operational cost-effectiveness
- Quality job creation
- Economic development

Environmental benefits include

- Significant reductions in GHG emissions that could assist with global climate change objectives
- Reduced public health risks

- Reduced impacts on the state's natural resources from energy generation and consumption

Security benefits include

- Reductions in natural gas imports
- Reduction in the reliance of natural gas production and delivery

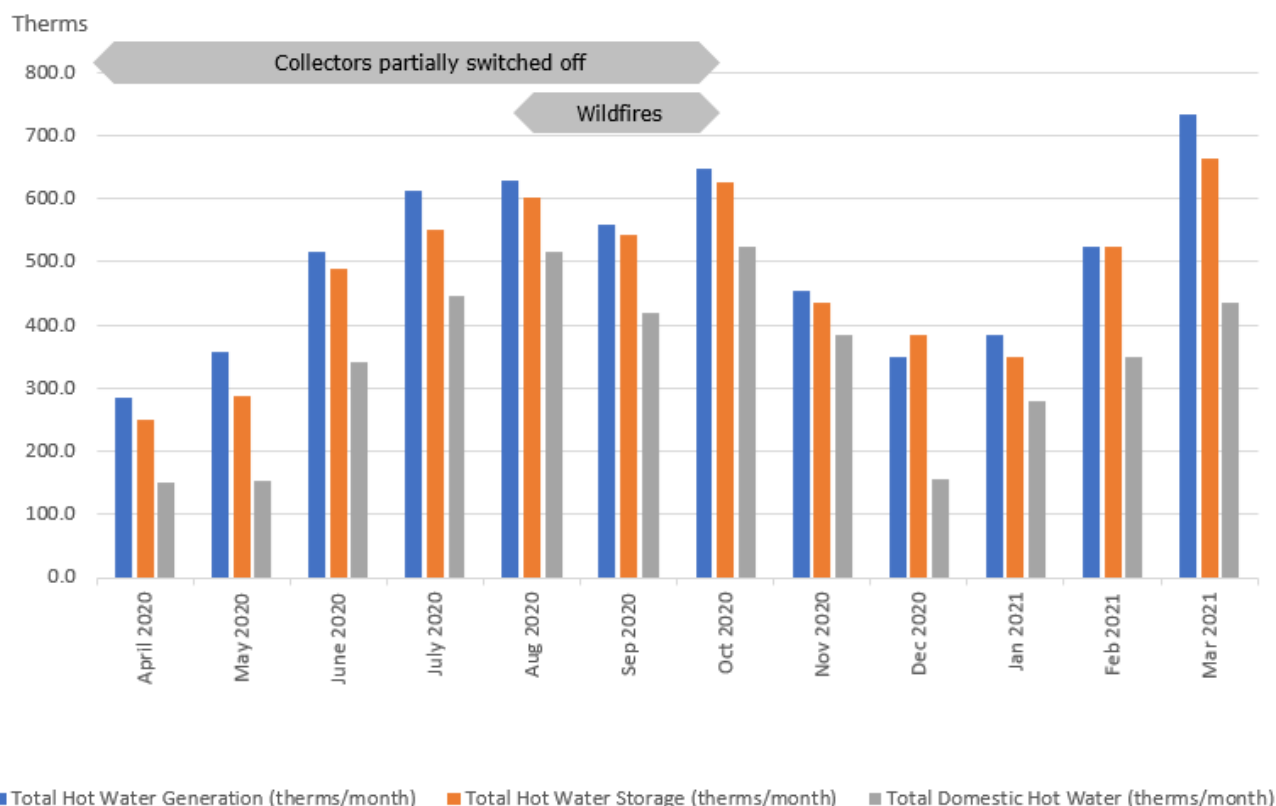
The heat demand plays a significant role in the industrial energy demand. In California's \$50 billion food processing industry, more than 600 million therms of natural gas are consumed annually (CEC 2008). This industry represents a very promising field of application for solar thermal technology. The project is expected to increase market acceptance, and due to the system's replicability and scalability to other plants and similar settings across California and elsewhere, will increase market penetration. The ergSol research project indicates that the ISTS has the capacity to save about 13,200 therms of NG per year, based on 82% boiler efficiency assumptions according to the California Solar Initiative Thermal Program (CSIT). This accounts for 70.2 metric tons of local GHG emission reductions. Assuming 30 percent of the natural gas use in the food processing sector could be offset by solar thermal, the natural gas savings would be 180 million therms per year, reducing GHG emissions by 955,800 metric tons. However, guidelines for the integration of large solar heating systems in industrial settings would be beneficial for accelerating market penetration.

Any rises in industrial natural gas prices will have a significant economic impact on companies and industrial units which have high NG consumption for process heat requirements. Given the challenges for California's NG infrastructure, the emission reduction policy requirements, the implication of high renewable natural gas costs into the gas pipelines, electrification activities, and power shutoffs, higher gas costs will be certain, but the cost increases are not yet known. Solar thermal provides process heat for displacing the use of NG and will decrease the operating costs and carbon emissions for industrial users. It could provide long-term hedging against fuel price volatility. Increased attention at the state and regional levels on integrated solar thermal systems in combination with thermal storage, cooling application, and financial incentives will boost the interest in this technology.

Additional Data Collection – April 2020 to March 2021

Despite the end of the contracting period, ongoing performance data from the data logger was collected and analyzed to assess the performance of the solar thermal system. The numbers are based on 30-second data collected from April 2020 through March 2021. The analysis shows that the generation and storage from the solar system is greater than the domestic water usage. This can be seen in Figure 25.

Figure 25: Monthly Hot Water System Loads (Generation, Storage, and CIP)



Source: ergSol, Inc.

Measurement & Verification methodology approach and assumptions were used as detailed in Chapter 3 - Project Results. The actual energy data (Table 7) is based on: Emission Factor (CO₂e) of 11.7 lbs/therm saved and industrial sector natural gas costs of \$0.92/therm were used as outlined in GFO-16-502 Attachment 13–References for Calculating Energy End-Use, Electricity Demand and GHG Emissions (CEC 2016).

Table 7: Actual Energy Data (entire year)

	Annual Generation (MMBtu/yr)	Offset Natural Gas Savings (therms/yr)	Avoided Costs (\$/yr)	CO ₂ Emission Reductions (metric tons/yr)
Expected Results (96% boiler efficiency)	1,084	11,291	\$10,387	60
Installed System Performance	605	4,156	\$3,824	22

Source: ergSol, Inc.

Comparing the installed system performance with the expected results, the installed system produced 56 percent of the expected annual generation and did offset 37 percent of the expected natural gas use. The offset natural gas is calculated by how much thermal energy is transferred to the CIP process water. This is dependent on how much water is being used by

the TWE process. The offset natural gas use is extrapolated from the actual CIP use for the same time period, which is using 69 percent of the solar thermal energy generated during the trend period.

- The 56% is the annual generation of the installed system as a fraction of the expected results
- The 37% is the offset natural gas of the installed system as a fraction of the expected results
- The 69% (updated) is the fraction of the total generation that is being used by the domestic hot water system.

The deviation between the expected results (Table 4) and the actual energy data from the installed system (Table 7) was affected by various circumstances:

a) Due to wildfires in California, in the first two weeks of September 2020, the solar-powered electric generation declined nearly 30% (EIA 2020). Wildfire smoke contains small, airborne particulate matter particles that are generally 2.5 micrometers or smaller (referred to as PM_{2.5}). This matter reduces the amount of sunlight that reaches the collectors, decreasing the heat energy generation. The pollution reached a record high of 659 micrograms per cubic meter on September 15, 2020. The project site in Sonoma was impacted by wildfires burning in Northern California from August 17 through October 8, 2020.

b) During the ongoing analysis of the CIP process and the domestic hot water consumption at TWE, approximately 50% of the solar thermal collectors were switched off from April through October, to adjust to lower domestic hot water demands.

c) The lower domestic hot water usage across the plant is directly related to the plant production capacity. The solar system was sized for a volume output that has not been actualized since installation.

There is an ongoing analysis of how to fully use the production from the solar thermal system for optimization. TWE will be exploring the use of solar thermal across its business. The technology has several uses that could benefit the supply chain for TWE.

LIST OF ACRONYMS

Term	Definition
ARB	Air Resources Board
C	Celsius
CEC	California Energy Commission
CIP	Clean-in-place
CPC	Compound Parabolic Concentrator
CSIT	California Solar Initiative Thermal
CO ₂	Carbon Dioxide
DHW	Domestic Hot Water
ETC	Evacuated Tube Collector
EJ	Exajoules
F	Fahrenheit
GHG	Greenhouse Gas
IAW	Industrial, Agriculture and Water
ISTS	Integrated Solar Thermal System
K	Kelvin
M & V	Measurement and Verification
NG	Natural Gas
RNG	Renewable Natural Gas
O&M	Operating and Maintenance
SIPH	Solar Industrial Process Heat
SRCC	Solar Ratings and Certification Corporation
ST	Solar Thermal
TAC	Technical Advisory Committee
TWE	Treasury Wine Estates

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